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Electrical and Photographic Compensation

Kodachrome Prints

Noise Reduction for Direct Playback

Compliance of Film Loops

Auditory Perspective

Color Television

TV Picture Sharpness

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Electrical and Photographic Compensation in Television Film Reproduction

By P. J. HERBST, R. O. DREW and S. W. JOHNSON

THE REPRODUCTION of filmed material over the television system seldom approaches the quality of direct projection. The degradation in quality is usually apparent as loss of detail, compression in both the highlights and the shadows, increased fluctuation noise and the introduction of spurious signals in the form of shading, edge flare, spots and halo. Loss of detail and distortion of the contrast rendition can be reduced by the employment of electrical compensation. Such methods have been employed with varying degrees of success. The extent to which they can be used is limited by the aggravation of noise and spurious signals. Conventional photographic processes do not permit an increase in detail to be achieved while attempts to minimize the compression of the highlights and shadows by reducing the range of the positive transparency to be televised are accompanied by loss of resolution due to the lowered contrast in the fine detail.

Aperture Loss

The characteristics of the television system have been subjected to a comprehensive analysis by O. H. Schade.[1–4] In this analysis, the loss in resolution is considered as aperture loss and an effective scanning aperture is established for each part of the system, including both the electrical and the photographic elements. This provides a means of comparing the resolving power of such diversified factors as spot size, frequency response, bandwidth, lens sharpness and emulsion resolution.

The aperture loss in a television system is basically the same effect which occurs in the optical recording of sound on film with a slit of finite width. This effect has been thoroughly discussed by E. D. Cook[5] (in 1930). The effect may be illustrated by the simple case of a uniform rectangular aperture traveling across an area which consists of alternate black and white lines of equal width. The distortion and loss introduced by the finite dimensions of the aperture are shown in Fig. 1.

The relation of the rectangular aperture to lines of several widths is shown at (a) in this figure. The fraction of the aperture area exposed to the white lines as the aperture progresses across the image is shown at (b). In order to provide a better concept of the subjective effect, the light flux through the aperture as it passes across lines having a 10:1 contrast ratio is shown at (c). It will be seen that all detail is somewhat degraded by a subjective widening of the white lines due to the distortion of the transition edges, and

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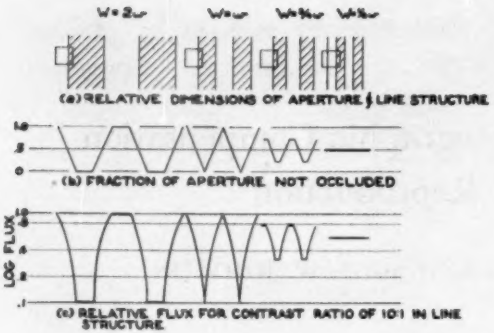

(a) RELATIVE DIMENSIONS OF APERTURE & LINE STRUCTURE
(b) FRACTION OF APERTURE NOT OCCLUDED
LOG FLUX
(c) RELATIVE FLUX FOR CONTRAST RATIO OF 10:1 IN LINE STRUCTURE

Fig. 1. Aperture flux (rectangular aperture).

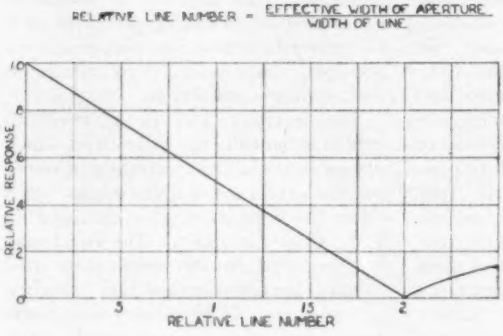
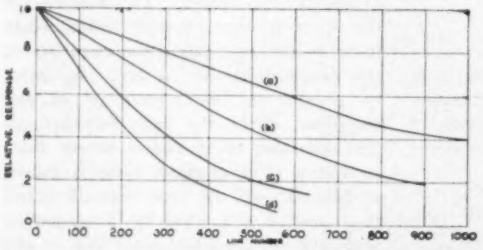


Fig. 2. Effective aperture response for square aperture.



(a) High quality experimental flying spot scanner (limiting resolution 2500 lines)
(b) Best iconoscope performance (limiting resolution 1200 lines)
(c) Image orthicon (5655) and 2-in. vidicon (limiting resolution 800 lines)
(d) Lowest iconoscope performance and 1-in. vidicon (limiting resolution 600 lines)

Fig. 3. Effective aperture response of television pickup tubes.

that the peak-to-peak ratio drops rapidly when the width of the lines becomes less than the width of the scanning aperture, reaching zero when the width of the lines is one-half that of the aperture. The relative detail contrast may be obtained by integrating the waves shown at (b) over a half-cycle. Since the eye, when viewing fine detail, integrates a portion of the transition in obtaining the sensation of maximum and minimum brightness, this method provides a measure of the apparent reduction in the ratio of the contrast between these two levels. The observed effect is the same as that produced when viewing lines of the original width but of lesser contrast. This is the equivalent square-wave response and determines the loss of detail in the system. (See Ref. 2, p. 250.)

Figure 2 shows the calculated aperture response for a rectangular aperture. The gradual loss in effective resolution is apparent in this figure.

In the television system, the effective apertures are essentially circular in shape and are not uniform in cross section. This, however, does not affect the application of this concept although the shape of the transition from black to white changes. The effective aperture response for several types of television pickup tubes is shown in Fig. 3. These curves do not include the losses of the camera lens or other parts of the television system. They represent the range of characteristics in pickup devices which may find application in televising motion picture film. A comprehensive discussion of aperture flux response factors is given by Schade.[2]

When several effective apertures are successively introduced into the system each contributes to degradation in detail. The method of computing the effective overall aperture for a number of apertures in cascade has been treated by Cawein.[6] This method is quite accurate for linear regions of the aperture response characteristics and states that the square of the effective aperture width of a number of cascaded apertures is equal to the sum of the squares of the individual aperture widths. Schade[2] applies the same process but performs the calculation in terms of the line number at which a given aperture response is obtained. In this case the square of the reciprocal of the line number of the system is equal to the sum of the squares of the reciprocals of the line numbers of the separate apertures producing the same relative response. This method has been employed to compute the effective aperture response of the system when televising 35-mm and 16-mm film. Figure 4 shows the calculated overall response including the losses introduced by the optical elements, the photographic process, a high-quality monitor and the television pickup tube. In this case a limiting resolution of 800 lines was assumed for the pickup device as representative of the performance realizable in current operations. The equivalent response of direct projected film is plotted to the same scale for comparison. In this figure the line number represents television lines, i.e., both black and white lines are counted.

Electrical Aperture Compensation

It is apparent that fine detail in the television system corresponds to high frequencies in the video signal. The aperture loss is therefore equivalent to a reduction in the amplitude response as the frequency increases. In sound reproduction such losses are frequently corrected by employing electrical networks which emphasize the higher frequencies and it appears possible to employ similar techniques in television equipment. Thus, "high-peaking" circuits are used to accentuate the higher video frequencies in both transmitting and receiving apparatus. Since this does not affect the separation between scanning lines, it is effective only in the horizontal direction and does not afford an increase in vertical detail.

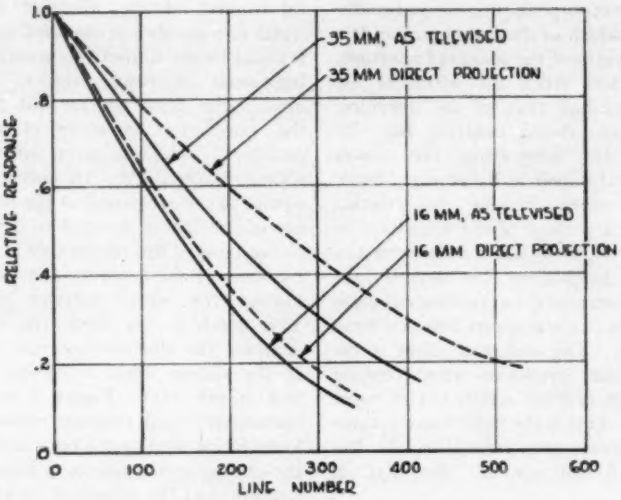


Fig. 4. Effective aperture response of television film (no compensation); limiting resolution of 800 lines assumed for pickup tubes; includes optical and photographic losses.

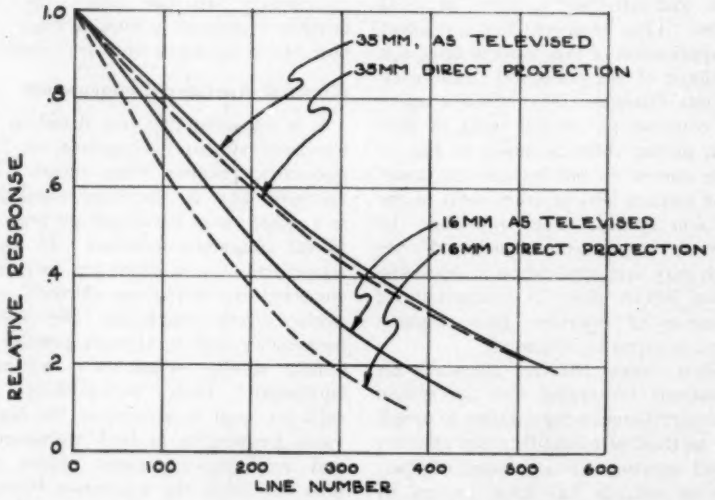


Fig. 5. Effective aperture response of television film (after compensation); limiting resolution of 800 lines assumed for pickup tubes; includes optical and photographic losses.

In a system of finite bandwidth such circuits produce transients or overshoots which appear in the image as white edges following black areas and vice versa. The effect is equivalent to the edge effects produced by some photographic processes. In the television system both the phase and the amplitude characteristics of the compensating circuit must be adjusted in order to obtain optimum compensation. When overcompensation is introduced into the system the transient effect produces an unnatural "relief" appearance which is highly objectionable. The optimum compensation which can be applied is determined by subjective effects and a complete evaluation remains to be accomplished. The effective aperture response of the television film process when the line number for a given response is increased by $\sqrt{2}$ is shown in Fig. 5. It will be noted that if this aperture correction could be employed the detail in televised film would exceed the detail obtained in direct projection. Unfortunately, the extent to which such compensation can be applied is limited by the extent to which the noise in the picture is increased.

System Noise

Noise in the signal from various pickup devices is of three types. In devices which do not employ electron multipliers the noise originates in the grid circuit of the first amplifying stage and is therefore independent of the amplitude of the video signal. The energy distribution over the video spectrum is not uniform but increases with frequency. Although this high-frequency noise is less perceptible by the eye, the application of electrical aperture compensation tends to greater accentuation of this type of noise. The iconoscope and the vidicon are both devices of this type.

The noise in the signal from image orthicons originates in the random fluctuations of the scanning beam. Since the signal is derived from a small modulation of this beam, the noise is independent of signal amplitude. It is uniformly distributed over the video spectrum and might therefore be considered as permitting more aperture compensation to be employed than in the case of amplifier limited devices. However, it has been observed that the disturbance becomes more objectionable as the frequency decreases and that the compensation required to compensate properly for aperture response usually extends into this region. The exact weight to be assigned to the subjective effect produced by different types of noise has not as yet been agreed upon. In practice the difference, as it applies to the extent to which correction can be employed, has been found negligible.

The flying spot scanner also produces noise which is uniform over the video spectrum. In this case, however, the noise originates from random emission of photoelectrons rather than from fluctuations in a comparatively large beam current. The noise amplitude is therefore proportional to the square root of the signal current. The extent to which aperture correction can be employed is limited by the same considerations as apply in the case of the image orthicon.

The actual signal-to-noise ratio will vary with the type of tube employed, the excellence of the particular unit and the conditions under which it is operated. Various measurements of camera-tube noise have been reported in the literature.[3(p.524),7] The subjective difference between "peaked" and "flat" noise prevents a precise comparison between tube types. However, qualitative differences in the degree to which corrective techniques may be applied can be obtained by employing these published figures as a basis. A fair average of the signal-to-noise in the maximum highlight signal appears to be 100:1 for the iconoscope, the vidicon and the flying spot scanner. This approximation is therefore employed in the further comparison of compensation

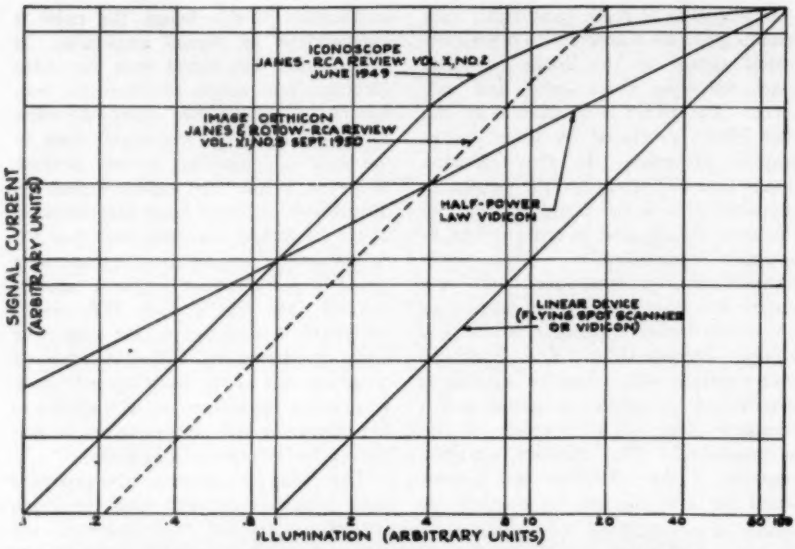


Fig. 6. Representative transfer characteristics of various types of television pickup devices.

as applied to these devices. The noise level of the present types of image orthicons is somewhat higher, especially when the tube is operated below the "knee" of its transfer characteristic. For example, the Type 5655 signal-to-noise ratio can be expected to lie between 35 and 50 to 1. Experimental image orthicons have been built in which signal-to-noise ratios exceeding 100:1 have been measured.

Transfer Characteristics of Television Pickup Tubes

Compression in both highlights and shadows in the transmission of film material over the television system is due to nonlinearity of the transfer characteristics of the camera tubes and the monitors and to the limited range which can be accommodated by the system. The transfer characteristics of several types of pickup devices are plotted in Fig. 6. The characteristic given for the iconoscope is representative of the general shape of the response curve but is subject in practice to wide departures with the average lighting and the distribution of illumination. The characteristic shown for the image orthicon is likewise merely representative since, in practice, the actual characteristic will depend upon the extent to which the highlights extend beyond the knee of the curve. The dynamic light-transfer characteristics of image orthicons has been treated by Janes and Rotow[8] and found to vary considerably with background illumination. The curve shown represents a static characteristic and seems to indicate that no contrast will be obtained in the highlights. However, the discharge of the target areas adjacent to highlights reduces the potential of these areas and provides the differential signal representative of detail. When the highlights are permitted to exceed the knee of the transfer characteristic by an appreciable amount, the redistribution effect produces objectionable halo, white objects being surrounded by black areas and detail

in light objects being almost entirely lacking. The present types of image orthicons are quite limited in the light range which they can successfully accommodate. A range of 30:1 appears to represent a practical operating limit. Under studio conditions, flat lighting and fill lights can be employed to realize this restricted range. The contrast range in most motion picture positives processed for direct projection is considerably in excess of the image orthicon capabilities. Moreover, under practical operating conditions the attention required to obtain optimum results is an objection. For these reasons the use of image orthicons of the currently available types for film pickup does not appear to be highly attractive at this time. Consideration will therefore be confined to the characteristics provided by the iconoscope, the vidicon and the flying spot scanner.

The transfer characteristic of the flying spot scanner is linear, i.e., it has a slope of unity when plotted on logarithmic coordinates. The present vidicons employed in industrial devices also have a linear transfer characteristic. A recent research being conducted at the RCA Laboratories under the direction of Dr. A. Rose makes the ultimate realization of a half-power law for the vidicon appear hopeful.

Contrast Rendition Over the Television System

In photography the contrast rendition in the final print is determined by the combined sensitometric characteristics of both negative and positive, by the maximum contrast which can be achieved, and by the flare light introduced by the printing process. The video signal from the television pickup device is modified in a similar manner by the characteristics of the video amplifier and the viewing monitor. The contribution of these various devices to the overall transfer characteristic is illustrated in Fig. 7.

In this illustration it will be noted that the viewing kinescope has a characteristic which follows a cubic response but is limited by flare light which is produced by dispersion in the phosphor and internal reflections in the glass face plate. When viewed in a darkened room a range in the order of 100:1 in screen luminance may be realized. Ambient illumination under more normal viewing conditions will result in considerable reduction in this range. It will be noted that under the best viewing conditions the range of the video signal which produces the maximum useful range of kinescope screen luminance is approximately 10:1. This depends to a large extent upon the level established for black signal. The extent of the variations has been discussed by Schade.[12]

In this diagram the transfer characteristics of the overall system have been constructed by transferring the relative signal current to the plot of the amplifier characteristic to find the relative grid signal applied to the kinescope, then transferring this to the kinescope characteristic to determine the screen luminance and plotting this value over the original point on the camera characteristic. The dotted line shows the process for one point on the characteristic obtained from an iconoscope and a linear amplifier.

This diagram shows the excessive white compression usually obtained from an uncompensated iconoscope. It also shows the extreme compression of the shadows and excessively high contrast in the remainder of the tonal range which is obtained from an uncompensated linear device. It will also be seen that the characteristic obtained with a device having a half-power law response is a fair approximation of the selected corrected response.

The amplifier characteristics required to compensate the characteristics shown at (a), (b) and (c) in Fig. 7 to the response indicated at (d) are plotted

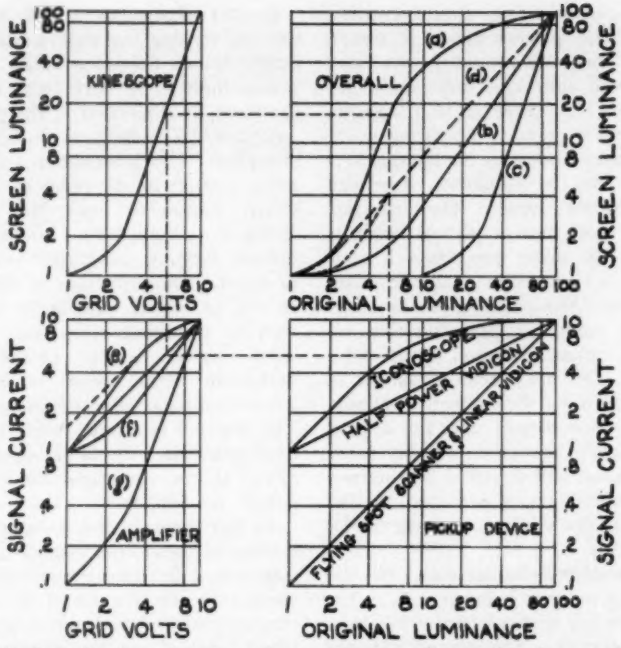


Fig. 7. Contribution of system elements to overall transfer characteristics.

(a) Overall response with iconoscope and linear amplifier
(b) Overall response with half-power law vidicon and linear amplifier
(c) Overall response with linear device (ex: flying spot scanner) and linear amplifier
(d) Overall characteristic after correction
(e) Amplifier response for correcting iconoscope characteristic
(f) Amplifier response for correcting half-power law characteristic
(g) Amplifier response for correcting characteristic of linear pickup device
NOTE: Broken parts of (d) & (e) illustrate effect of simple "white" stretching.

(All quantities in arbitrary units)

at (e), (f) and (g), respectively. In order to provide a simple method of relating the various characteristics to the overall system response the positions of the dependent and independent variables have been inverted from their usual relationships in plotting the amplifier characteristics. Partial compensation of the transfer characteristic obtained with an iconoscope has been obtained by expanding the signal in the range corresponding to the highlights. The design and performance of such amplifiers has been discussed by Goodale and Townsend.[9] When the system employs simple "white stretching," the lower portion of the amplifier characteristic is linear. The characteristic of such an amplifier is shown by the dotted departure from Curve (e). The effect is to provide better rendition of the highlights at some expense in overall range and the distortion of the characteristic in the shadows as shown by the dotted departure from Curve (d). The transfer characteristics of the compensating amplifiers are plotted on a linear scale in

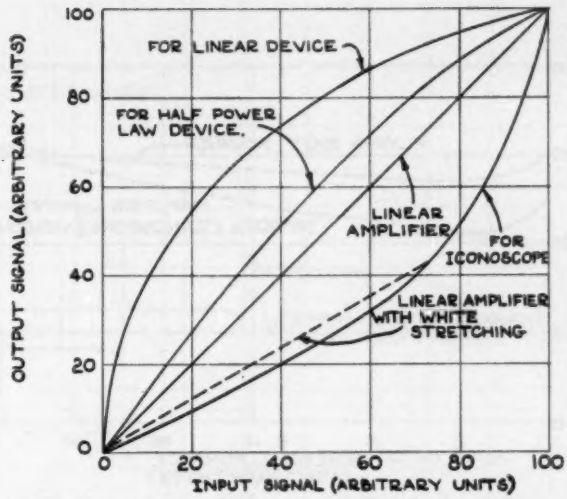


Fig. 8. Transfer characteristics of correcting amplifiers.

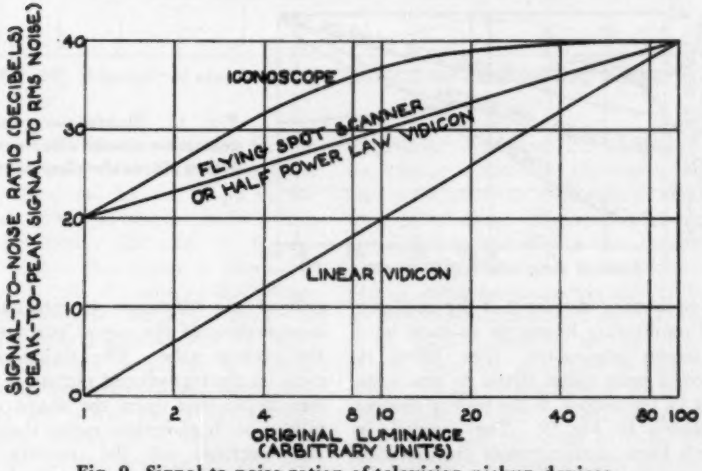


Fig. 9. Signal-to-noise ration of television pickup devices.

Fig. 8. The extent to which such compensation of the transfer characteristic can be employed again depends to a large extent upon the increase in noise level. Depending upon the luminance range in which they appear, spurious signals may also be aggravated by such compensation.

Effect of Electrical Compensation on Noise

Assuming that the various television pickup devices are capable of providing a signal-to-noise ratio of 100:1 in the highlights the fluctuation noise in the reproduced picture may be calculated

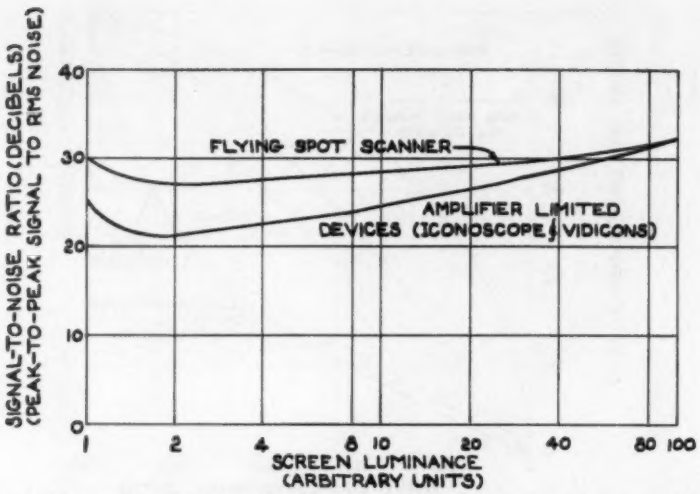


Fig. 10. Fluctuation noise in television screen (no compensation-linear amplifier).

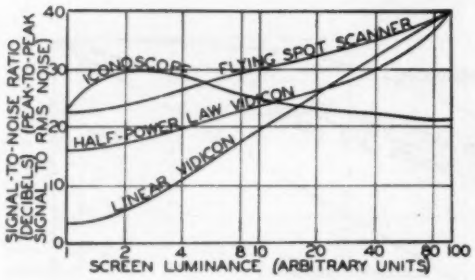


Fig. 11. Fluctuation noise in television screen after compensation of transfer characteristics.

by considering the slopes of the amplifier and monitoring kinescope at each level of screen luminance. The effect in terms of peak video signal to rms noise level in the output of the pickup devices is shown in Fig. 9. The manner in which these characteristics are modified by the transfer characteristic of the monitoring kinescope is illustrated in Fig. 10 which shows the calculated fluctuation noise plotted against kinescope screen luminance. Because the screen luminance is used as the abscissa there is no difference between the apparent noise from any of the amplitude limited devices. This is because the amplitude of the noise applied to the grid of the kinescope is constant and independent of the signal current from the pickup tube. The signal-to-noise ratio in the reproduced picture is therefore dependent upon the shape of the kinescope characteristic rather than upon the response of the camera tube employed. It will be noted that the combination of the reduced camera noise at lower signal levels and the reduced slope of the kinescope characteristic in this region result in an improved signal-to-noise ratio in the shadows. This plot does not indicate the serious distortions in contrast rendition which accompany the use of uncompensated linear devices.

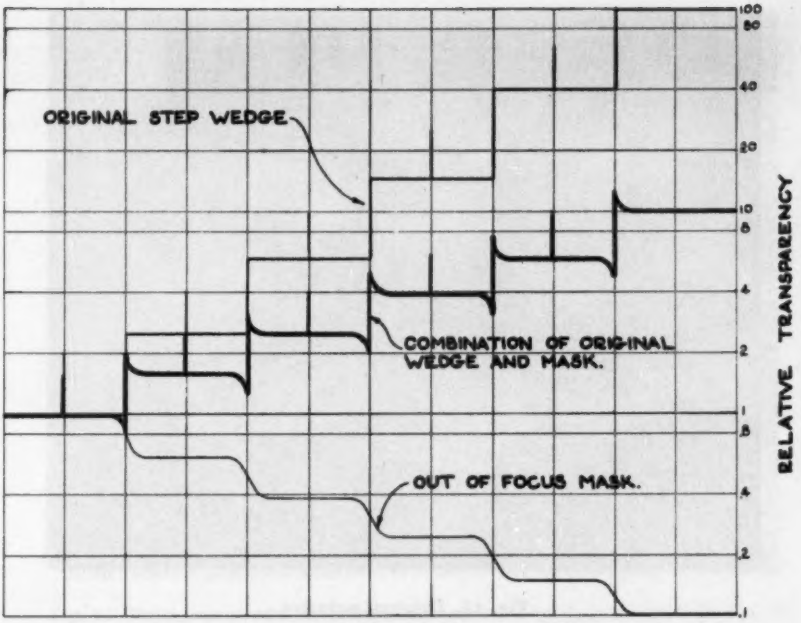


Fig. 12. Principle of area masking illustrated by detail on step wedge.

When electrical compensation for the transfer characteristic is introduced the noise is modified by the slope of the amplifier characteristic at each screen brightness level. The effect in the reproduced television image is illustrated in Fig. 11. In the case of the iconoscope the amplifier slope is reduced in the shadows and increased in the highlights. The net result is a serious increase in the noise in the highlights. The opposite is true for the other types of pickup devices all of which require expansion of the lowlight signals and compression of the signal in the highlights. The very serious increase in apparent noise in the shadows in the case of a linear device which is limited by amplifier noise is shown by the characteristic for the linear vidicon.

The subjective difference between noise in the highlights and noise in the shadows has not been considered in this discussion. Likewise, the curvature of the kinescope screen in the region of the highlights has been neglected in making these calculations. The results, however, are sufficient to indicate that the tolerance in apparent noise is insufficient to permit optimum compensation for both transfer characteristic and aperture losses to be applied without serious increase in the apparent graininess of the television image. Improvement in the signal-to-noise ratio of the pickup devices will raise the level of these noise characteristics without greatly modifying their general shape.

Photographic Area Masking

Working in a different field, G. L. Dimmick and H. E. Haynes found that the tonal range in high-contrast prints could be successfully reduced without impairment of the detail contrast and suggested that this technique, which has

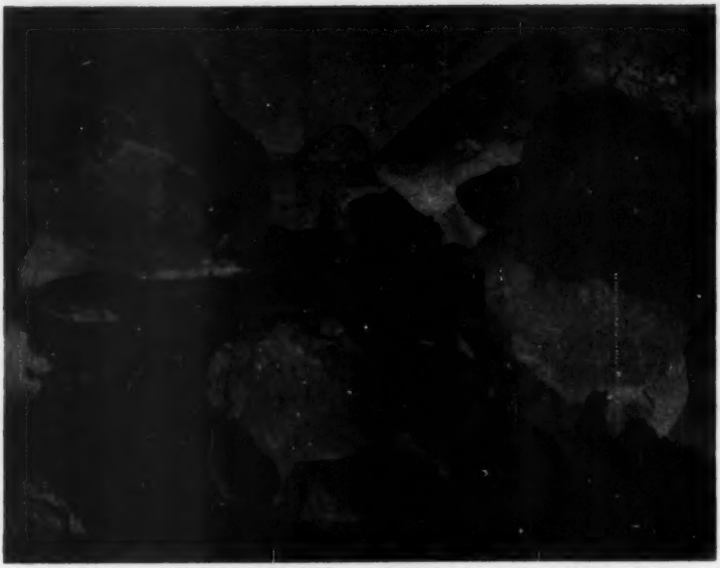


Fig. 13. Original negative.

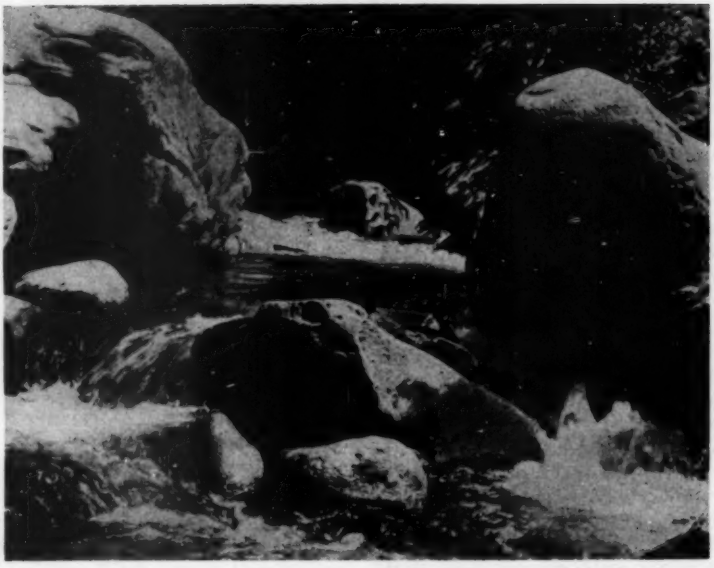


Fig. 14. Normal contrast print from negative in Fig. 13.

Fig. 15. Print processed to lower than normal contrast from negative in Fig. 13.

Fig. 16. Unsharp mask from original negative in Fig. 13.

been applied to some extent in the graphic arts, might be applied to television reproduction with equal success. A brief investigation disclosed that this photographic method could be advantageously applied to the processing of prints intended for transmission over the television system.

The technique which is known as "Area Masking" is not new since there is evidence that it was described by German experimenters as early as 1931. More recent work with unsharp masks was described by M. J. Johnson[10] in 1943, while a review of the principles and methods of obtaining the effect was published by J. A. C. Yule of Eastman Kodak Co. in 1945.[11] Recently, this method has found some application in the graphic arts where it is often necessary to reduce the wide tonal range of a picture from contrast ratios of 100:1 or greater in the properly processed transparency to a range of 20:1 or less for proper reproduction within the limitations of papers and inks. The limitations of the television system impose similar restrictions on the tonal range which can be adequately accommodated since, although the previous discussion referred to realizable ranges of 100:1 these can only be achieved under the most favorable conditions and are seldom attained in practice. A more realistic range of 30:1 seems to coincide with current informed opinion. Since motion picture positives, properly processed for direct projection, frequently contain ranges of contrast in excess of 150:1 the conditions for televised film are similar to those encountered in the reproduction of pictorial material by half-tone printing.

A mask may be considered as a photographic image which is superimposed on another photographic image to alter the characteristics of the final reproduction. If a positive transparency, processed to a low control gamma, is placed over the negative from which it was made, the contrast range is less than that in the original, and prints made from this combination on normal print stock with normal processing will contain a reduced contrast range. If the mask is in sharp focus and exact register, the net effect is that of processing the final print to a lower control gamma. However, if the image is intentionally defocused when the mask is made, the large area contrast will be reduced but the detail contrast will remain unchanged since the mask in any given area will act as a neutral filter for sharp detail, reducing the exposure of the final transparency but not affecting the detail contrast ratio. Such an unsharp mask can be made by separating the emulsion, which will constitute the mask, from the negative during exposure by a distance sufficient to produce appreciable blurring.

The principle may be illustrated by considering the effect on a step wedge having fine detail in each step. In Fig. 12 the original step wedge is considered to consist of five equal logarithmic steps covering a total overall contrast range o 100:1. The fine detail in this wedge is represented by the edges and the fine lines centered in each step. The unsharp mask is represented as having an overall contrast range of 10:1. The edges are reproduced by gradual transitions since the image is out of focus, while the fine detail in the center essentially disappears. The combination of the original transparency and the mask produces a step wedge in which the overall contrast is 10:1 while the contrast excursions at the edges and in the fine lines remain unchanged. It will be noted that in this figure the detail is shown as having a contrast excursion of one-half the contrast between successive steps in the original wedge. In the combination the detail contrast is equal to the contrast between steps while the edges are reproduced at the original contrast. This also serves to illustrate the edge effect which is produced by the process and which can result in extreme artificiality in the final transparency if the method is carried to extremes. In practice, it is

probable that the mask would be applied to the negative during the printing process. Under special circumstances the mask could be applied to the positive print when televised.

The television engineer will recognize the analogy to "high peaking" which is employed in electrical aperture compensation. The edge effects are similar to those produced by the transients or "overshoots" in electrical networks. Schade[4] has pointed out this analogy and treated the effect in some detail. Yule[11] has pointed out that this accentuation of the edges is similar to the subjective response of the eye when viewing adjacent contrasting areas and does not impair the natural appearance of the reproduced image unless excessively aggravated.

The process may be likened to automatic dodging during the printing process, each area being given the proper exposure to place it in the desired region of a reduced tonal scale. In effect, the process gives the impression of more even scene lighting while permitting natural illumination during the filming of the original scene. The method requires the production of an extra print and adds another step in the photographic process. The resultant improvement in the quality of the televised film appears to justify this additional effort.

The exact parameters to be applied during processing have not, as yet, been determined. However, the method does not appear to be critical since the very first attempts met with excellent success. The degree of defocusing which will be optimum for reproduction over the television system may be different from that which is best suited to direct viewing of an opaque print. The possible overaccentuation of detail contrast to compensate for aperture losses in the television system remains to be investigated. Because the mask is appreciably out of focus, serious registration problems are not anticipated and have not constituted a difficulty in the tests made to date. There seem to be no special difficulties in the employment of the process to obtain prints better suited to the characteristics of the system although further refinements may provide improved means of control and closer realization of optimum quality.

It will be noted that the process accomplishes the desired reduction in excessive contrast and compensation for aperture losses in one photographic step and that this is accomplished without any increase in noise except for the additional film graininess introduced by the mask. In our experiments this increase in grain has not been noticeable. The method therefore allows greater latitude for the introduction of such remaining compensation of transfer characteristic by electrical means as may be considered desirable.

Pictorial Effect of Area Masking

The effect on the picture quality can be judged from a series of reproductions made from 35-mm transparencies. It should be borne in mind that the illustrations shown here are half-tone reproductions of glossy paper prints which in turn were made from original transparencies. Transparencies demonstrate the principle of photographic area masking effectively but much information has been lost in the glossy print and half-tone processes which seriously limit the contrast range. Figure 13 is an original 35-mm normal contrast negative. A direct-contact print taken from this negative and processed for direct projection was found to have a transmission range of 130:1 (Fig. 14). This print is too contrasty to reproduce well over the television system. Figure 15 shows the effect of processing the print to lower than normal contrast. In this print, the overall contrast range was reduced to 10:1. It will be noted that the detail is lacking and the extreme flatness produces a chalky or veiled appearance.

Figure 16 shows a positive unsharp mask which when combined with the original negative produces a contrast range

Fig. 17. Area masked print from original negative in Fig. 13 and unsharp mask in Fig. 16.

Fig. 18. Photographic reproduction of the original normal contrast transparency of Fig. 14 over an iconoscope television system.

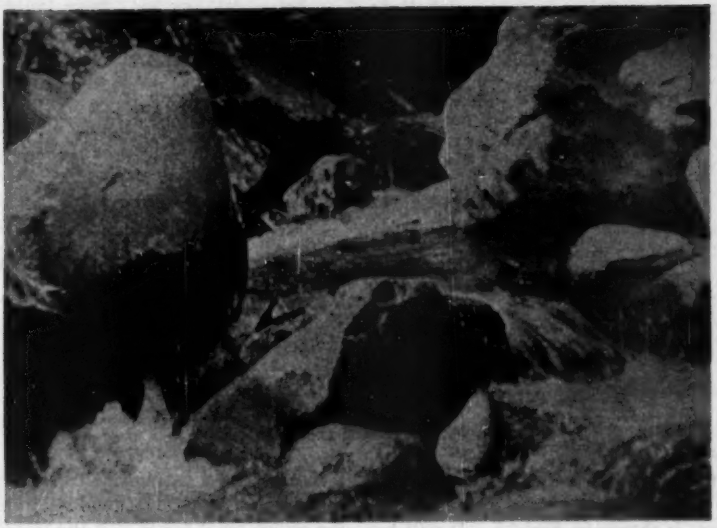


Fig. 19. Photographic reproduction of low contrast transparency of Fig. 15 over an iconocsope television system.

Fig. 20. Photographic reproduction of area masked transparency of Fig. 17 over an iconoscope television system.

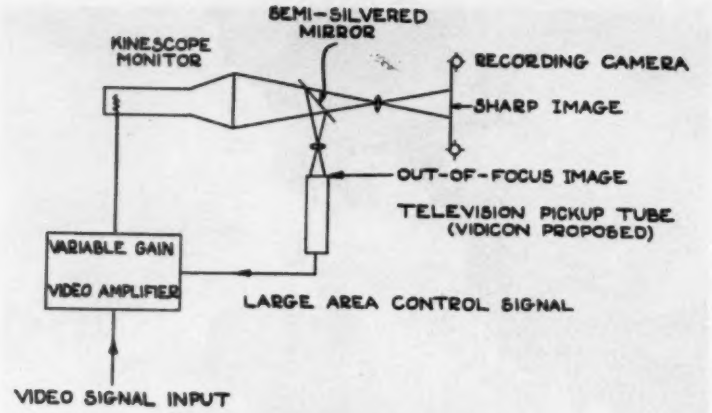


Fig. 21. Electrical area masking.

of 10:1 in a normally processed print. The print obtained by this area masking process is shown in Fig. 17. It will be noted that although the tonal range is the same as in the print made by reduction of the control gamma, the detail contrast is unimpaired. Although the appearance in direct projection is not as pleasing as the more contrasty original print, the fine detail is retained and the picture still has the quality loosely termed "snap" or "crispness."

The reproduction of the original normal contrast transparency shown in Fig. 14 over an iconoscope channel is shown in Fig. 18. This is a photograph of a 5-inch monitor having a P11 phosphor and operated over the optimum range of its characteristic. A 4 × 5-in. still camera was employed to eliminate any losses in detail by the recording process. It will be noted that both the highlights and the shadows are excessively compressed. Figure 19 is a photograph of the same monitor when the low-contrast transparency shown in Fig. 15 is televised over the same channel. The only change in the settings was to increase the gain to obtain the same video signal at the grid of the kinescope. The loss of detail is very apparent, especially in the highlights. Figure 20 is the result of televising the area masked transparency shown in Fig. 17. The good rendition of the entire tonal range and the improvement in detail are apparent.

The method, in its present state of development, has recently been demonstrated to representatives of several broadcasting companies who expressed considerable interest in its possibilities. Efforts are currently under way to apply the technique to both 16-mm and 35-mm motion picture film. It is of particular value in cases where access to the original negative is possible such as in the case of preparing advertising trailers and other material intended solely for reproduction over the television system.

It should be noted that the method is applicable to electrical circuits. One method of applying the technique to video recording is illustrated in Fig. 21. This is a block diagram showing the recording camera disposed properly in front of the kinescope monitor. By means of a semi-silvered mirror or other light-splitting device an out-of-focus image is focused on the photosensitive surface of a pickup tube. The signal from this tube represents the contrast in the large areas and is used to control the gain of an amplifying device. This circuit is equivalent in its operation to the

photographic mask. It will be noted that the gain varies with the signal level produced by the larger picture areas but is constant at any level as regards the higher-frequency signals representing the fine detail. The full advantage of the masking technique in achieving compensation without aggravating the noise is not realized in the simple circuit illustrated in Fig. 21.

Conclusion

The characteristics employed in this discussion are given as representative of the performance of several types of television pickup devices. In practice, wide variations may be observed. The actual measured figure of aperture response, transfer characteristic and signal-to-noise ratio may differ from those given since individual tubes and the conditions of operation are variable. Furthermore, further improvements in tube performance may modify any specific conclusions drawn from the foregoing.

At the present time the limitations of the television system make some form of compensation highly desirable. Unfortunately, currently available elements do not provide sufficient latitude for the incorporation of optimum electrical compensation. The principle of area masking therefore appears to offer attractive possibilities especially in the preparation of motion picture positives specifically intended for transmission over the television system.

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Processing 16-Mm Kodachrome Prints

By WILLIAM HEDDEN, THOMAS WEAVER and LLOYD THOMPSON

In 1949, the Eastman Kodak Company agreed to license independent laboratories to process 16-mm Kodachrome film. The first machine for this purpose has been built by The Calvin Company, and has been in use since April 1, 1950. This paper gives a description of the machine, some of the problems encountered with the process, and some of the results obtained.

When Eastman Kodak Company arranged to license independent laboratories to process 16-mm Kodachrome film, The Calvin Company decided to construct such a machine for 5265 stock. This decision was made for several reasons:

(1) It was desirable that we eliminate the necessity of sending all printed duplicates to the Chicago laboratory of Eastman Kodak Company for processing, as this caused delays even though air freight was used in both directions.

(2) The cost of shipping this material back and forth by air, and the necessary telephone calls, etc., was expensive.

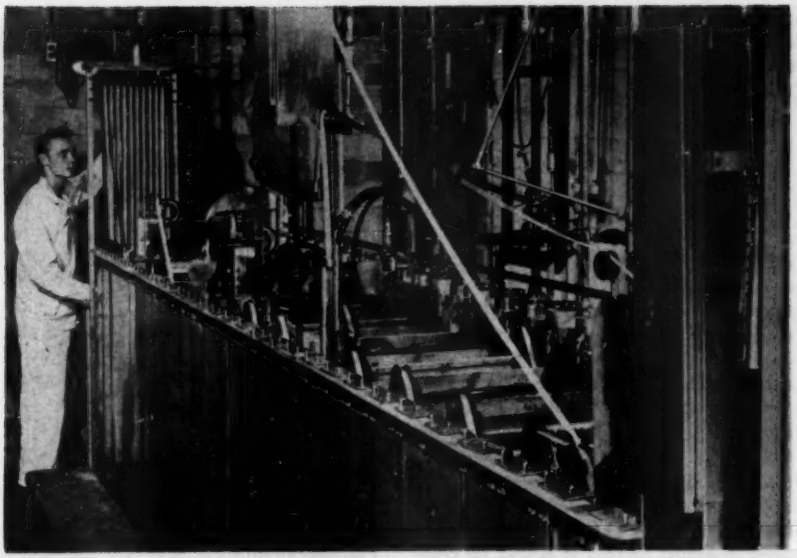
(3) It was believed that the control of processing quality within our own organization might lead to improved color quality in Kodachrome duplicates, because of closer coordination between printing and processing.

Presented on April 30, 1951, at the Society's Convention in New York, by William Hedden, Thomas Weaver and Lloyd Thompson, The Calvin Company, 1105 Truman Rd., Kansas City, Mo.

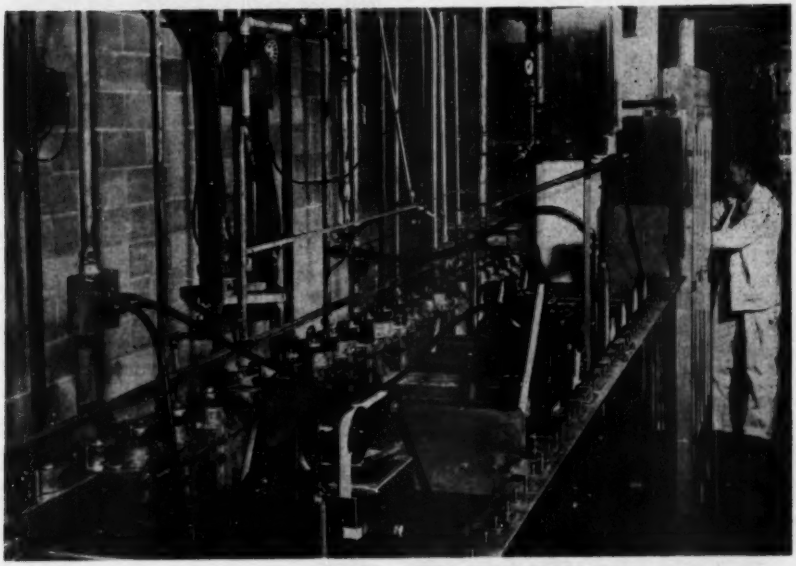
It was realized that this was a project of rather large scope. The installation would be difficult and expensive, and only a very limited amount of technical experience was available to independent laboratories. Such an installation would be somewhat different from the facilities of the Eastman laboratories, and no one could accurately predict what might happen.

The machine was planned and completed in about a year's time. Since April 1, 1950, all Kodachrome duplicates made by us have been processed in our own machine. While the basic processing information was made available by the Kodak Company in a manual for licensees, it was decided to modify the machine design.

We felt the Kodachrome machine should be built on the same basic design as our black-and-white machines, so that operators familiar with the black-and-white equipment could also run the color machine. Such a machine was easier for us to build, and certain parts were interchangeable with the black-and-



General view of Kodachrome processing machine.



Looking toward dry end of machine. In the foreground can be seen one of the color printers with the second one in about the center of the machine.

white machines. It was decided to operate our equipment at higher machine speed than the Kodak machines, in order to get additional production capacity.

After gathering as much information as possible, Bob Sutton and our Engineering Department proceeded to make a layout of a machine based on the information released by Eastman Kodak Company, and similar to our black-and-white processing machines which were originally designed following the plan of the Ansco black-and-white machine. This machine is an adaption of the modified Spohr-Thompson bottom-rack drive, and runs at 62 fpm.

Developing time of the various solutions was a factor in determining tank size, and the number of racks necessary for operation. A few extra tanks were added as a safety factor in event of a processing change. The racks and tanks were designed so that it would be comparatively easy to change tanks in order to make timing or processing solution changes.

The machine as finally constructed consists of nineteen stainless steel (type 316) tanks. The ferricyanide bleach tank is lead lined, and the rack in the bleach is made of red brass. Twenty-nine racks are used in normal operation of the process. A 2-hp, 3-phase motor supplies the power through a belt to the drive shaft. The drive shaft consists of a length of 1-in. shafting with one worm gear at each rack position enclosed in a sealed oil-filled gear case. Each worm gear drives a spur gear, and another spur gear is placed on this shaft above the gear case. When the racks are in position on the machine, the upper rack gear is meshed with the spur gear outside the gear case, and this drives the rack. Pins are used to keep the racks in proper position. Individual racks can be removed from the machine simply by lifting them out.

The bottom rollers of the drying cabinet are driven by means of a chain drive attached to the end of the main drive shaft. The drying cabinet uses a closed circuit of air in order to maintain the proper drying conditions. The humidity is controlled by the use of a Frigidaire sealed ½-hp condensing unit. The condenser and the compressor unit are mounted in the air stream, reheating the air after it has been dehumidified by the cooling coil. This unit in conjunction with electric strip heaters, a blower and control instruments, maintains a constant relative humidity of 50% at a temperature of 85 F.

The feed cabinet at the head of the machine is large enough to permit storage of stock for almost two minutes before the elevator reaches the top.

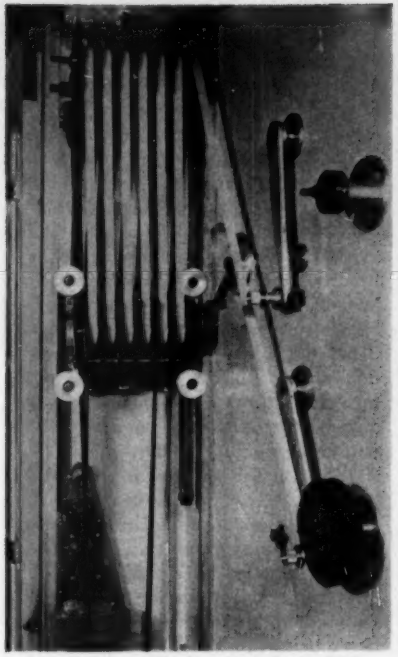
The take-off elevator is equipped with a brake which prevents rollback when take-off pressure stops. The take-off spools are driven by a torque motor to maintain constant take-up pressure. The motor has a separate operating switch so that it may be shut off momentarily while the film is being changed from one spool to another—during that time the elevator takes up the film.

The basic rack used in the machine is made of stainless steel angles, hard rubber rollers and Synthane bearings. Separators are placed between each of the 19 bottom drive rollers to prevent looping. The upper 20 rollers are fitted loosely to their shaft, and the total capacity of each rack is 126 ft.

To aid in the removal of the antihalation backing of the film, buffer rollers are installed in the first three washes. A Canton flannel-covered wooden roller is suspended between the top and bottom rollers of a rack. This roller, driven by the rack drive shaft in the same direction of film travel, buffs the film base removing all the backing.

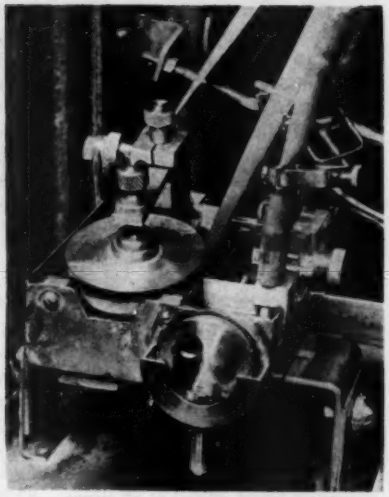
It is necessary to expose the cyan and yellow layer in the film separately before color developing; therefore, it was essential that we build a cyan and yellow printer.

In the Kodak processing machine the film runs horizontally over the printers,



Waxer, elevator and take-ups. Take-ups are driven by torque motor.

but the printer which was designed for our machine was built so that the film travels in a vertical position. Basically the printer consists of a lamp, centering light through an intergrading bar and filter, exposing the film as it travels through a masked channel. Power for the lamp is fed from transformers and adjusted by means of a Variac transformer. The intensity is measured with a foot-candle meter, and also checked by the means of an ammeter. An Aklo glass was installed in the blue printer to prevent heat from cracking the filter. Blowers are installed on each printer to carry off the heat from the lamp. An air squeegee is used before the film enters the sound applicator, and another is used just before it enters the drying cabinet. At several points throughout the machine



Mechanism for applying sodium sulfide to sound-track area.

small rubber wiper squeegees are used to prevent dilution and carryover from one tank to another.

Perhaps the most difficult processing operation to perfect was the sound track application. To develop the sound track on Kodachrome prints the film passes edgewise on an applicator wheel, while a sulfide sound developing solution is applied just to the edge area of the picture by a wiper knife blade or pen. This is done just before the magenta developing solution. After the sound developing solution has reacted a few seconds it is necessary to wash it from the film immediately to prevent any sulfide sound solution from fogging the picture area. Several methods of doing this were tried before a satisfactory system was found. The problem was finally solved by the use of vertical wash jets hitting the film at an angle, which allowed the water to flow across the track area and off the film immediately. While a manual of instructions was supplied by Eastman Kodak Company, the increased speed of our machine presented

an application problem not encountered on machines operating at lower speed. With an efficient squeegee before the sound applicator, the film was still too moist when it entered, and uneven application of the sulfide sound solution resulted. To overcome this problem it was necessary to use one of the extra tanks and racks as a dry box, which we call the "hot rack." The film is dried enough so that uniform sound application is possible. Once these problems were solved, very little trouble has been encountered with sound application.

Constant replenishment of the solutions is accomplished by the means of adding solutions controlled by stainless steel needle valves, and measured through a Stabilvis Flowrator which measures and shows the exact amount of replenisher being added at all times. This mixes with the tank solution being recirculated just before it enters the pump. It is then filtered, passed through a heat exchanger and another Flowrator which shows the rate of circulation, and then enters the system by means of a pipe at the bottom of the tank. Any excess developer which is not used overflows into the sewer by means of a pipe at the desired tank level.

A small pot made of stainless steel is placed on the system between the replenisher valve and the recirculation pump for the addition of chemicals for process correction while the system is in operation. By using this method, it is possible for the Control Department to make additions from the outside of the processing room. It also insures proper mixing and minimizes the danger of streaking film by improper handling.

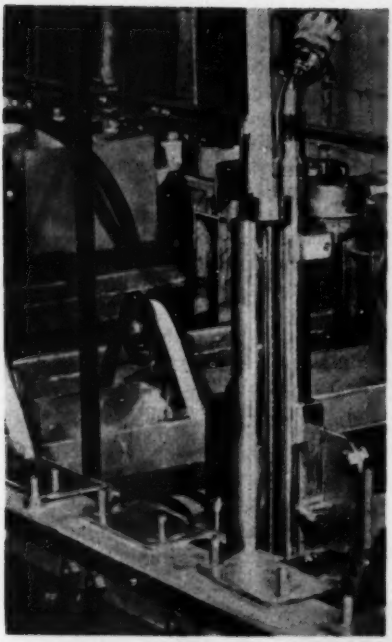
Brown temperature controls are used to maintain temperature within plus or minus one-half degree at 80 F. All solutions, including the wash water, are automatically controlled at 80 F. Automatic temperature control devices are used to mix the proper amount of cold and hot water to maintain the temperature of solution and wash water.

The amount of wash water being used in each tank is also accurately controlled, and measured by Flowrators. All the developer solutions are recirculated and filtered with the exception of the prehardener, ferricyanide bleach, and hypo.

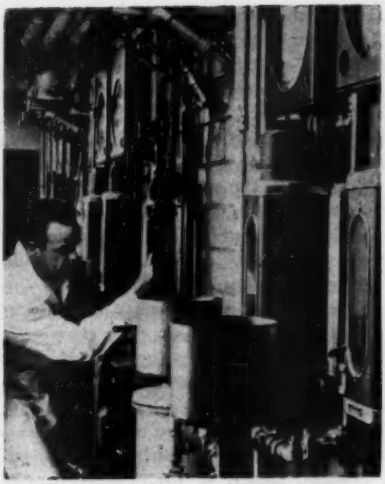
The filter is a cast-iron pot with a clamp-tight cover. The insert, or filter, consists of a perforated stainless-steel tubular holder, covered with a fine stainless-steel screen. This is wrapped with Filtocot, and finally a layer of gauze is tied around the outside to prevent any cotton from coming loose and getting into the system. The pump forces the solution around and through the filtering material to the center of the holder where it leaves through a pipe connected to the bottom of the filter holder.

The replenisher solutions are mixed in stainless steel mixing tanks on the floor above the processing machine, and flow to the machine by gravity. Each mixing tank is provided with a reserve tank of sufficient size to provide the machine with replenisher while a new tank of solution is being mixed. Lighting mixers are provided for all mixing tanks. The bleach tank is lead-lined and equipped with Saran pipes and red brass valves. Ventilation is provided for the scales used in weighing organic developers and couplers.

In order to get a consistent process it is necessary to provide regular maintenance. During the first month of operation considerable machine maintenance was required, due to the formation of organic tars in some color developers. These tars required that the color developer racks be removed from the machine each night for cleaning, and cleaning tanks were designed for this purpose. One tank holds an acid-alcohol bath, and the other a water-rinse bath. However, improvements in the process during the last year, along with operating experience in handling color developers, has greatly reduced the tar formation originally encountered. These improvements reduced the amount of rack clean-



Jet wash for removing sodium sulfide from sound track before processing continues.



Part of the control instruments to regulate temperature, rate of replenishing and rate of agitation.

ing necessary, and have decreased much of the rack maintenance which was required when the racks received a great deal of handling.

It has been found that frequent filter changes in the solution recirculating system are good economy. Clean filters provide solutions which are free from tar and sediment—and not only provide cleaner, more even development, but are also a factor in reducing rack cleaning and maintenance. Other parts of the machine must be given regular maintenance and cleaning in order to insure accurate readings and accurate performance. Filter changing and gauze cleaning are regular maintenance.

Color processing introduced the necessity of protecting operating personnel from skin irritation, or dermatitis, arising from the use of particular types of organic chemicals. Eastman Kodak Company provided considerable information and suggestions for protection in the use of chemicals, and by following these suggestions explicitly, dermatitis has not been a problem. Naturally, a few people had to learn the hard way, but once they learned it simply was not a problem.

A problem was presented in the disposal of used filter packing. Used packing is saturated with organic tars and concentrated developing by-products. Special disposal procedures were required to prevent skin irritation to those outside the company handling this refuse.

Usually the best black-and-white film operators graduate to the color machine, after being trained as black-and-white film operators. Although operation of color and black-and-white machines is generally similar, color processing requires more detailed machine work, and generally more alert operation than does black-and-white processing.

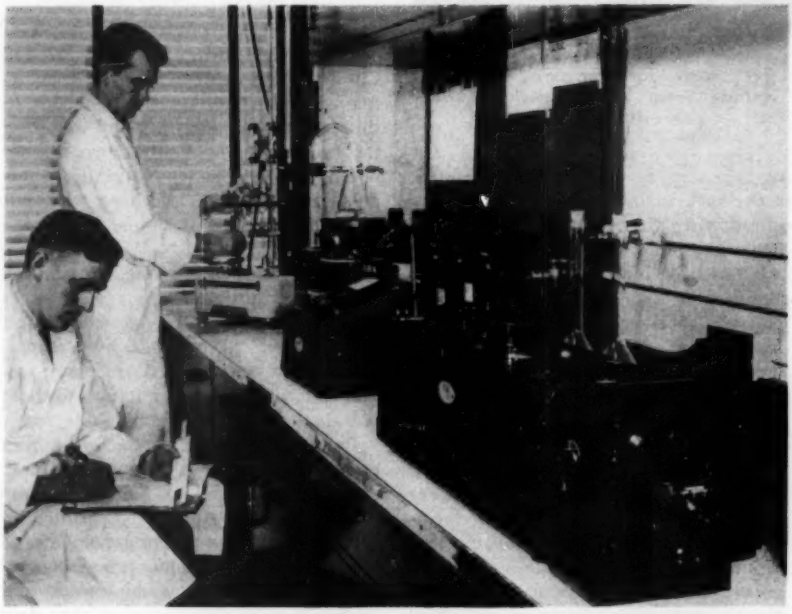
The importance of responsible solution-mixing men was established early in our color processing experience. While small errors may not necessarily be serious in black-and-white mixing, they become disastrous in color. Inaccurate solution mixing often will not appear as trouble until the solution has been in use for several hours, thus presenting difficult problems of trouble shooting and correction which may result in considerable loss of production processing time.

Specially trained chemists for solution control and analysis are also necessary. Analysis of replenishers immediately after mixing and before use is desirable, as is regular analysis of tank concentration. Analytical personnel are especially valuable when trouble shooting is required.

Color control is perhaps the most important processing responsibility. Usually supervisory personnel undertake this control work. They must be thoroughly trained in all phases of color processing, and have complete knowledge and experience in the operation of the machine and other equipment used.

Specifically, our control procedure consists of three steps: Sensitometric tests, picture strips, and print inspection. Drum-printed sensitometric tests are processed regularly, read on an Ansco color densitometer and recorded. Backing up this sensitometric information are printed picture strips developed with each sensitometric test.

Occasionally these picture strips show conditions not interpretable on the sensitometric test, and this is extremely practical for quality checking. Visual inspection of prints as soon after processing as possible is another valuable and practical method of quality control. Inspection also provides a quick check on the printing operation. By combining information obtained from these three sources,



A part of the chemical control laboratory.

it is possible to hold Kodachrome print quality within narrow and acceptable limits.

We use one group of printers, one processing machine, and by having both the printing and processing of Kodachrome film within the same laboratory, it has been possible to achieve noticeable improvement in the consistency of color quality release printing. Such consistency is noticeable in regular printing, but it shows up immediately and noticeably when it is necessary to print hard to reproduce material, such as to make prints from masters.

It would not be proper to end this paper without mentioning a few of the people who have been extremely helpful in the project from the very beginning, although it will not be possible to list them all. We were very fortunate in having Bob Sutton and Ken Curtis in our Engineering Department, along with the men who helped them in building and installing the machine. Besides the authors, Dale Musselman spent a great deal of time and thought in getting the process started, maintaining quality, and turning out production in a minimum length of time with a minimum amount of spoilage. The men who actually run the machine and mix the chemicals have been very interested in the process, and very helpful in their suggestions so that the best possible results could be obtained. It would be impossible to name personally all the people at the Eastman Kodak Company who have helped and encouraged us in getting the machine built and into operation. And, we would like to acknowledge and thank them and also the men at Ansco for their interest and suggestions in this project.

We feel the project has been a success, and perhaps the greatest factor in that success is the pride of achievement felt by each person working on it.

A System of Double Noise Reduction for Variable-Area Recording for Direct-Playback Purposes

By J. G. STREIFFERT

In variable-area recordings made for direct-playback purposes, the density of the "opaque" part of the track is established by distortion criteria and is usually so low that the signal-to-noise ratio is adversely affected. A system of "double noise reduction" is proposed which does not require the use of auxiliary lamps, slits or galvanometers. By this means, not only is the clear area of the track reduced during periods of low modulation, but also the density of the exposed area of the track outside the modulation envelope is increased in order to reduce the noise contributed by this part of the track. Tests indicate that a reduction in noise of 3 to 4 db can be expected.

IT IS WELL KNOWN that when variable-area recordings are made for direct-playback purposes, the density of the "opaque" portion of the track is usually undesirably low (1.0 or less), if the requirement of minimum distortion is met. Under these conditions, during reproduction a substantial fraction of the incident light gets through the semi-opaque part of the track and adversely affects the signal-to-noise ratio. To ameliorate this difficulty, it has been proposed by Robinson,[1] Dimmick[2] and others,[3] that what might be called "double noise reduction" be used. A drawing illustrating what this type of track would look like is shown in Fig. 1. The clear area of the track would be reduced during periods of low modulation by application of noise-reduction currents to the recording galvanometer as is the custom in making direct-playback recordings. In addition, the outer portions of the track are made completely opaque by subjecting the region outside the modulation envelope to a higher-intensity exposure than the region which carries the modulation. Previous proposals for accomplishing this end have required the use of one or more auxiliary items, such as lamps, slits, galvanometers, etc., to lay down *successive* exposures. The proposals which follow indicate means for achieving the required differential in exposure in the two parts of the track *simultaneously* and with a minimum of complication and of modification.

The problem is that of realizing a higher-intensity exposure in the portion of the track which is normally occluded by the opaque noise-reduction shutter vanes than in the portion not occluded

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Fig. 1. Drawing of a variable-area direct-positive recording with double noise reduction.

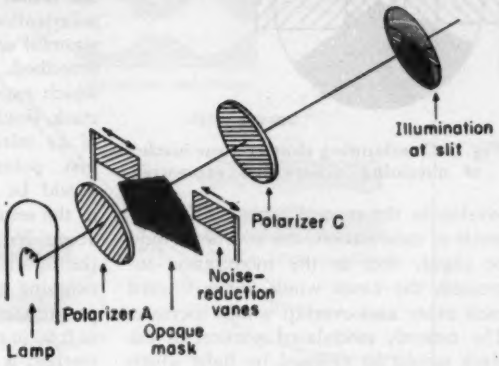

Fig. 2A. Disposition of polarizers in optical system to produce higher intensity of exposure in outer portions of track than in central portions.

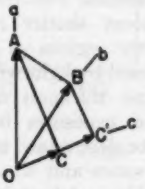

Fig. 2B. Vectorial representation of light intensity after passing through 2 or 3 polarizers.

by the vanes. Several solutions of this problem are suggested.

In Figure 2A, polarizing means are shown in the condenser system on either side of the noise-reduction shutter vanes. In addition, the noise-reduction shutter vanes are made of either polarizing film or of a birefringent material, such as mica, which produces circularly or elliptically polarized light. The two polarizing disks are adjusted for partial extinction. By proper orientation of the two disks relative to the shutter vanes, a condition is realized wherein the light intensity is greater where the beam traverses all three polarizing films than when it traverses only the two disks. This is shown vectorially in Figure 2B. If Oa represents the plane of polarization of polarizer A, and Oc that of polarizer C, then the intensity of light passing through these polarizers will be the projection of the vector, OA, on Oc, which is OC. However, where the light passes through the polarizing shutter vanes, the intensity is determined by the projection of OA and Ob, which is OB, and then the projection of OB on Oc, which is OC′. By adjusting the plane of polarization of the various polarizers, any ratio of intensity between OC and OC′ from zero to one can be attained. This provides a means for adjusting the relative exposures in the two exposed portions of the track.

Three other methods of attaining two exposure levels in the two parts of the track have been suggested by R.N. Carter.* These are shown in Fig. 3. In one method, the shutter vanes are made of semitransparent material and

* Patent Dept., Eastman Kodak Co.

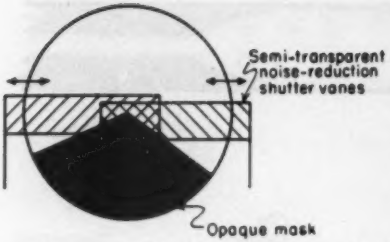

Fig. 3. Overlapping shutter-vane method of obtaining differential exposure.

overlap in the central region. For low levels of modulation, the overlap would be slight, and as the modulation increased, the vanes would move toward each other and overlap would increase. The central, modulated portion of the track would be exposed by light which had traversed two thicknesses of semitransparent shutter material, whereas the outer regions of the track would be exposed by light which had traversed only one thickness of material. The ratio of exposures in the two areas would be determined by the transmission of the vanes and would not be readily adjustable. Adjustability would not appear to be very important, however, since the density of the outer regions of the track would not be critical, the only requirement being that it be high enough to be substantially opaque, i.e., 2.0 to 2.5. If the photographic film is developed to a gamma of 3.0, this means that the outer regions of the track would have to have approximately four times the exposure of the modulated portions and that the shutter vanes would have to have a transmittance of 25%, or a density of 0.60.

The use of shutter vanes made of different colored filters has also been proposed. The difficulty of selecting different colored filters which give substantially identical exposure in the two outer portions of the track appears to make this method impractical.

Perhaps the most practical proposal is to make the two shutter vanes of polarizing material so oriented with respect to each other that where they overlap partial extinction occurs. The exposure ratio would again be fixed by the initial orientation of the planes of polarization. This system would be less wasteful of light than the other systems described. In this system, the light which exposes the outer regions of the track would be reduced to about 40% of its initial intensity, whereas in the first polarizing system described, it would be reduced to about 30% and in the semitransparent shutter system to about 25%. These figures imply that the optical system must be capable of exposing the film to a density of approximately 2.2 with a density of 0.40 to 0.60 in the beam, depending on which method is used.

In order to determine the improvement which might be expected from such a system of double noise reduction, recordings were made to simulate the effect. One-thousand-cycle signals were recorded at 5-db decrements in level from full modulation to 60 db below full modulation. From full modulation to 20 db below full modulation, the galvanometer was held in its normal, unbiased position, and the entire slit was covered with a 0.3 neutral-density filter. The exposure was adjusted to give a density of 1.0 under these conditions. The galvanometer was then tilted to produce a 0.005-in. septum on the film, and signal levels from 20 db to 60 db below full modulation were recorded, still with the neutral-density filter over the entire slit. This would correspond to maximum noise reduction as normally applied to direct positive recording, i.e., the clear area has been reduced to a minimum and the exposed area has a uniform density of 1.0. Then a duplicate of this last series of levels was recorded with the 0.3 neutral-density filter reduced in width so that it produced a 0.010-in. septum centered on the 0.005-in. septum produced by the galvanometer. By this means the

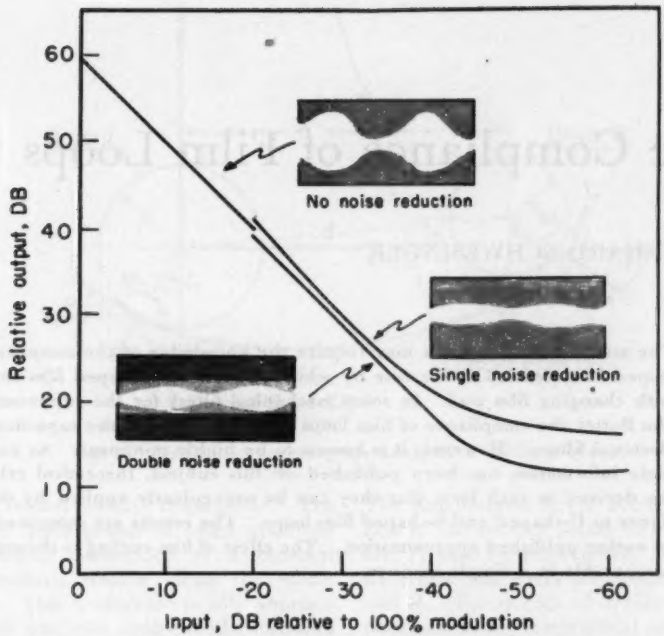

Fig. 4. Output versus input for direct-playback recordings with single and double noise reduction.

density outside the modulation was increased to about 2.0.

The output level of each section was then measured and plotted against the input level to the galvanometer. The noise spectrum was limited to the band between 500 and 8000 cycles/sec by means of high- and low-pass filters. The results are shown in Figure 4. It is seen that an improvement of from 3 to 4 db in signal-to-noise ratio could be expected from double noise reduction as compared to normal (single) noise reduction, when applied to the direct-playback type of variable-area recording. While this may not be a sensational improvement, it is clear that where a large amount of this type of recording is done, the improvement would be worth the complication.

Acknowledgment. The author expresses his gratitude to Mr. John Finkle, who made the recordings and collected the data presented here.

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The Compliance of Film Loops

By GERHARD SCHWESINGER

The analysis of film drives may require the knowledge of the compliance of looped film, defined as the rate by which the length of looped film changes with changing film pull. In some mechanical filters for the suppression of film flutter the compliance of film loops acts in analogy to the capacitance of electrical filters. However, it is known to be highly nonlinear. As no complete information has been published on this subject, theoretical relations are derived in such form that they can be conveniently applied by the designer to U-shaped and S-shaped film loops. The results are compared with an earlier published approximation. The effect of film curling is shown to be accountable in a simple manner.

In some types of film drives the elastic properties of looped film sections are of considerable importance. In particular, sound-film drives utilize these properties to filter out transient and periodic disturbances which by various causes may be impressed upon the steady motion of the film. An analysis of the filtering action then requires the knowledge of a relation between the film tension and the amount of slack film in a film loop, usually referred to as the elastance or, inversely, compliance of film loops. This relation has been experimentally investigated by E. D. Cook[1] who pointed out its nonlinear character.

The theoretical treatment of the film loop problem is mathematically more laborious than might be expected. Inherently it is a matter of analytical mechanics rather than motion picture engineering and this may explain why so far no complete information on this subject has been published for motion picture purposes. An earlier theoretical treatment is due to W. J. Albersheim and D. MacKenzie[2] who derived the first two terms of a series expansion for the film slack as measured between the inflection point of an S-shaped loop and one of the drums over which the film is wound. For practical application it is desired to know the total length of slack film at a certain film tension in the loop. This information is not explicitly contained in the quoted paper. The reader might try to derive it therefrom by generalization, but he remains in uncertainty as to the validity of the result. In fact, there is no simple additive relation between (a) the total slack and (b) the partial amounts of slack as measured from the inflection point of the S-loop to the first

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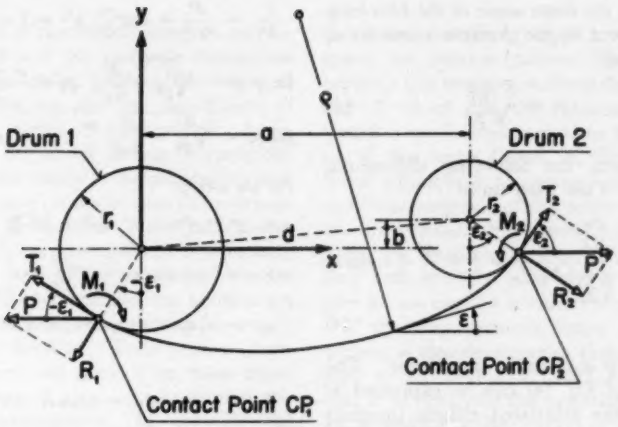

Fig. 1. Quantities entering the analysis of the loop curve.

and second drum, respectively. The earlier investigation[2] is based upon the simplifying assumption of a constant longitudinal tension along the whole loop. This assumption is only approximately true and, consequently, furnishes results of limited validity. In order to establish these limits and to complete the earlier results, the problem of film loop elastance will now be treated in a different way eliminating any arbitrary assumptions. The analysis will be extended on U-shaped loops which, having no inflection point, are not covered by the paper.[2]

While the exact solution of the loop problem can be derived in terms of elliptic integrals without much labor, it takes considerable mathematical reasoning to arrive at the first one or two members of a series expansion which alone is suitable for practical use. Unfortunately, we must say, the exact solution does not lend itself to quick numerical evaluation. It will be included here, however, for completeness and as basis of a simple approximation to be derived from it.

Figure 1 shows the two drums (1 and 2) around which the film is looped. The quantities related to one of these drums carry the subindex 1 or 2, respectively. The longitudinal forces acting on the film in the contact points CP_1 and CP_2 are T_1 and T_2, respectively. Likewise, the transversal forces are denoted by R_1 and R_2. For reasons of equilibrium the resultants of the longitudinal and transversal forces in each contact point must be equal as indicated by the equally long film pull vectors P. The bending moments in the contact points are M_1 and M_2. If EI is the bending stiffness of the film, i.e., the product of the modulus of elasticity E and the moment of inertia I of the cross section through the film, then

$$M_1 = \frac{EI}{r_1}; \qquad M_2 = \frac{EI}{r_2}. \tag{1}$$

The difference between the moments M_1 and M_2 is balanced by an additional moment arising from the parallel displacement of the opposing force vectors P relative to each other. The center of drum 1 is now chosen as origin of a coordinate system whose x-axis points opposite to the direction of the film pull P in the contact point CP_1. If the center coordinates of the drum 2 are called a and b, and the distance between the drum centers d, then

$$a^2 + b^2 = d^2. \tag{2}$$

Denoting the slope angle of the film loop with respect to the positive x-axis by ϵ, and setting

$$A = \sqrt{\frac{EI}{P}}, \tag{3}$$

one obtains the following differential equation of the loop curve

$$A^2 \frac{\frac{d^2y}{dx^2}}{\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{3/2}} = y + \frac{A^2}{r_1} + r_1 \cos \epsilon_1 \tag{4}$$

where A is a constant parameter. The solution of Eq. (4) can be expressed in terms of the tabulated elliptic integrals of the first kind, $F(k,\varphi)$, and second kind, $E(k,\varphi)$* (see Ref. 3). For briefness, the following notation will be used

$$[F]_\beta^\alpha = F(k,\alpha) - F(k,\beta);$$

$$[E]_\beta^\alpha = E(k,\alpha) - E(k,\beta).$$

If ρ is the radius of loop curvature and s_{12} the length of the film loop between the contact points CP_1 and CP_2, one can write the solution as follows.

For the U-loop:

$$x = r_1 \sin \epsilon_1 + A\left[\frac{1 + k'^2}{k} F - \frac{2}{k} E\right]_{\varphi_1}^{\varphi} \tag{5U}$$

$$y = -r_1 \cos \epsilon_1 - A^2\left(\frac{1}{r_1} - \frac{1}{\rho}\right) \tag{6U}$$

$$a = r_1 \sin \epsilon_1 - r_2 \sin \epsilon_2 + A\left[\frac{1 + k'^2}{k} F - \frac{2}{k} E\right]_{\varphi_1}^{\varphi_2} \tag{7U}$$

$$b = -r_1 \cos \epsilon_1 + r_2 \cos \epsilon_2 - A^2\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \tag{8U}$$

$$s_{12} = kA[F]_{\varphi_1}^{\varphi_2} \tag{9U}$$

$$\frac{1}{k^2} = \frac{A^2}{4r_1^2} + \cos^2 \frac{\epsilon_1}{2}; \; k'^2 = 1 - k^2 \tag{10U}$$

$$\sin \varphi = \sqrt{\frac{1}{k^2} - \frac{A^2}{4\rho^2}}; \; \varphi_1 = \frac{\pi + \epsilon_1}{2};$$

$$\sin \varphi_2 = \sqrt{\frac{1}{k^2} - \frac{A^2}{4r_2^2}}; \; \frac{\pi}{2} < \varphi_2 < \pi \tag{11U}$$

For the S-loop:

$$x = r_1 \sin \epsilon_1 + A[F - 2E]_{\varphi_1}^{\varphi} \tag{5S}$$

$$y = -r_1 \cos \epsilon_1 - A^2\left(\frac{1}{r_1} - \frac{1}{\rho}\right) \tag{6S}$$

$$a = r_1 \sin \epsilon_1 + r_2 \sin \epsilon_2 + A[F - 2E]_{\varphi_1}^{\varphi_2} \tag{7S}$$

$$b = -r_1 \cos \epsilon_1 - r_2 \cos \epsilon_2 - A^2\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \tag{8S}$$

$$s_{12} = A[F]_{\varphi_1}^{\varphi_2} \tag{9S}$$

$$\frac{1}{k^2} = \frac{A^2}{4r_1^2} + \cos^2 \frac{\epsilon_1}{2}; \; k'^2 = 1 - k^2 \tag{10S}$$

$$\cos \varphi = \frac{A}{2\rho}; \; \cos \varphi_1 = \frac{A}{2r_1}; \; \cos \varphi_2 = -\frac{A}{2r_2} \tag{11S}$$

It is seen that the coordinates x and y of the loop curve are expressed by parametric equations with the parameters φ, ρ, respectively, the former appearing as argument of elliptic integrals. By means of the Eq. (11U) or (11S) one of these parameters can be eliminated. It is further seen that the relations are not identical for the two loop forms, which means that further investigations must be carried out separately. There is one expression, however, which is found invariant in both loop shapes, namely

$$\cos \epsilon + \frac{A^2}{2\rho^2} = \cos \epsilon_1 + \frac{A^2}{2r_1^2} = \cos \epsilon_2 + \frac{A^2}{2r_2^2} = \text{const.} \tag{12}$$

The numerical evaluation of the foregoing equations is easy only if both components T and R of the film pull vector P are known in one of the contact points, say, CP_1. In this case one knows the angle ϵ_1 and, from Eq. (12), also ϵ_2. The

* E is the adopted standard notation for the elliptic integral of the second kind and also for the modulus of elasticity. Confusion will be avoided if it is kept in mind that the latter only occurs in the product EI, but never isolated.

modulus k of the elliptic integrals can be calculated and the integrals themselves taken from tables, yielding the length of looped film, s_{12}, and the coordinates of the loop curve. Unfortunately, however, it is by far not so easy to apply the above given results to the problem of film elastance as it occurs in sound-film drives. It should be recalled that in such drives the lateral force component R is usually unknown and of no particular interest for the designer because this component does not perform work during the steady motion of the film. Thus neither ϵ_1 nor ϵ_2 is known and there is no basis other than a guess of ϵ_1 or ϵ_2 for beginning numerical calculations. In general, the distance d between the drums is fixed and the length s_{12} of the film loop is to be determined in relation to the longitudinal force component T_1. Mathematically speaking, this would require first to solve for ϵ_1 the four equations, (2), (7), (8), and (12), containing the four unknown quantities a, b, ϵ_1, and ϵ_2, and, second, to substitute the result in Eq. (9), yielding the wanted length s_{12}. Due to the transcendental character of these equations an analytical solution is impossible. The numerical solution, on the other hand, becomes very tedious as it essentially amounts to a trial-and-error procedure.

The next step to be taken toward a simplified evaluation is a series expansion of the unwieldy solution given above. Since no arbitrary assumptions are necessary to do this, the accuracy of the result can be as high as desired, depending only on the number of series terms.

First, it should be noted that for given values of the bending stiffness EI, drum radii r_1 and r_2, and center distance d, the modulus k becomes a function of only one remaining independent variable. As such one can choose the film pull P or one of its components, either at the contact point CP_1 or CP_2. One can also choose the parameter A or one of the angles ϵ_1 and ϵ_2. The preferable choice is A because then the mathematical relations become symmetrical with respect to the drum indexes 1 and 2. Furthermore, for motion picture film of inherently low bending stiffness the parameter A which has the dimension of a length is small as compared to the length s_{12} of the loops found in film drives. Small values of A/s_{12} ensure a sufficiently rapid convergence of the series and permit one to establish explicitly, in a simple form, the relationship between k and A, or k' and A, which otherwise is too complex for an explicit solution.

If the loop becomes flatter as A decreases, ϵ_1 also decreases so that, with regard to Eq. (10U) or (10S), k tends to one, k' to zero, and the quantities φ_1 and φ_2, according to Eq. (11U) or (11S), to $\pi/2$. There exist simple approximations of the elliptic integrals in the vicinity of $k = 1$, $\varphi = \pi/2$, at which point they exhibit singularities. It can be shown that in this region

$$F(k,\varphi) = \ln \frac{1 + k \sin \varphi}{\sqrt{k'^2 + k^2 \cos^2 \varphi}}, \text{ and}$$

$$E(k,\varphi) = k \sin \varphi + \frac{k'^2}{2} F(k,\varphi) \qquad (13)$$

provided that

$$\cos^2 \varphi \geqslant \frac{k'}{1 + k'}. \qquad (13a)$$

Using the approximation (13) for $F(k, \varphi)$ in connection with Eq. (11U) and (11S), one can calculate the length s_{12} of the loop. One finds:

For the U-loop:

$$s_{12} = A \sqrt{1 - k'^2} \ln \frac{A^2}{r_1 r_2 k'^2} \qquad (14U)$$

For the S-loop:

$$s_{12} = A \ln \frac{4\sqrt{(k'^2 + A^2/4r_1^2)(k'^2 + A^2/4r_2^2)}}{k'^2}. \qquad (14S)$$

If A and k' tend to zero, i.e., if the film is pulled taut between the drums, the length of the flat loop becomes s_t as it appears from Figs. 2 and 3. In order to furnish this limit value, from (14U) and (14S), k' must satisfy the condition

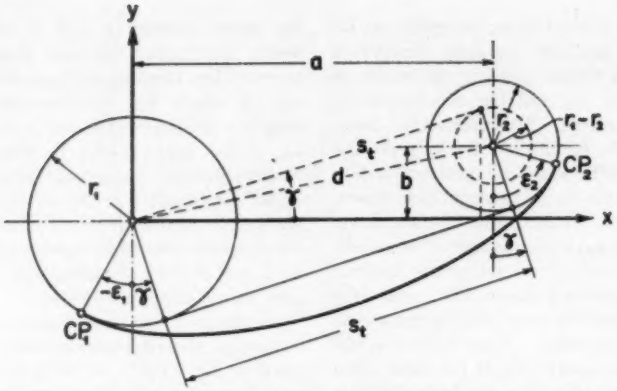

Fig. 2. Geometrical relations for calculating the slack in a U-loop.

$$k' = \frac{A}{\sqrt{r_1 r_2}} \exp\left(-\frac{s_t}{2A}\right). \quad (15)$$

It is seen that k' tends infinitely faster to zero than A. Therefore in all later expansions terms in k' are negligible as compared to terms in A with the exception of the term

$$M = k'^2[F]_{\varphi_1}^{\varphi_2}$$

which is not always negligible because $[F]_{\varphi_1}^{\varphi_2}$ tends to ∞. Applying the relation (15) to the approximation (13) for $E(k,\varphi)$, one obtains identically for both loop shapes

$$[E]_{\varphi_1}^{\varphi_2} = \frac{A^2}{8}\left(\frac{1}{r_1^2} + \frac{1}{r_2^2}\right) + \frac{A^4}{128}\left(\frac{1}{r_1^4} + \frac{1}{r_2^4}\right) + \tfrac{1}{2}M + \ldots. \quad (16)$$

From Figs. 2 and 3 one can read the length S of slack film in the loop as follows:

U-loop:

$$S = s_{12} - s_t - r_1(-\epsilon_1 + \gamma) - r_2(\epsilon_2 - \gamma) \quad (17U)$$

S-loop:

$$S = s_{12} - s_t - r_1(-\epsilon_1 + \gamma) - r_2(-\epsilon_2 + \gamma) \quad (17S)$$

Eliminating $[F]_{\varphi_1}^{\varphi_2}$ and a from the sets of Eqs. (2), (7U), and (9U), and Eqs. (2), (7S), and (9S), respectively, one obtains expressions for s_{12} which, substituted in Eq. (17U) and (17S), respectively, furnish:

For the U-loop:

$$S = \frac{k^2}{1+k'^2}\sqrt{d^2 - b^2} - s_t + (r_2 - r_1)\gamma + \frac{2Ak}{1+k'^2}[E]_{\varphi_1}^{\varphi_2} + r_1\left(\epsilon_1 - \frac{k^2 \sin\epsilon_1}{1+k'^2}\right) - r_2\left(\epsilon_2 - \frac{k^2 \sin\epsilon_2}{1+k'^2}\right).$$

Apart from negligibly small terms of the order k'^4 the last equation is equivalent to

$$S = \sqrt{d^2 - b^2} - s_t + (r_2 - r_1)\gamma + 2A[E]_{\varphi_1}^{\varphi_2} - 2AM + r_1(\epsilon_1 - \sin\epsilon_1) - r_2(\epsilon_2 - \sin\epsilon_2) \ldots (18U)$$

For the S-loop:

$$S = \sqrt{d^2 - b^2} - s_t - (r_1 + r_2)\gamma + 2A[E]_{\varphi_1}^{\varphi_2} + r_1(\epsilon_1 - \sin\epsilon_1) + r_2(\epsilon_2 - \sin\epsilon_2) \quad (18S)$$

Eqs. (8U) and (8S), for the center ordinate b, can be transformed so that b appears as function of A. One has only to remove ϵ_1 and ϵ_2 by aid of Eqs. (10) and (12). Since in flat loops k'^2 is a negligibly small quantity, the following formula holds

$$b = -r_1 \pm r_2 - \frac{A^2}{2}\left(\frac{1}{r_1} \mp \frac{1}{r_2}\right) \quad (19)$$

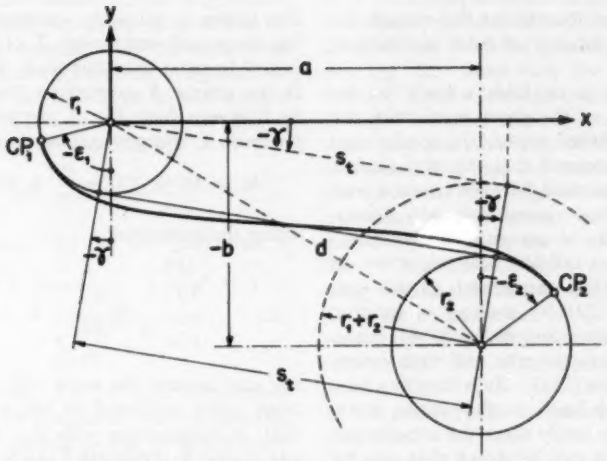

Fig. 3. Geometrical relations for calculating the slack in an S-loop.

The upper sign is to be taken for U-loops, the lower sign for S-loops. From Figs. 2 and 3 the length s_t and the angle γ are obtained as follows.

$$s_t = \sqrt{d^2 - (r_1 \mp r_2)^2}, \tag{20}$$

$$\sin \gamma = \frac{b s_t + (r_1 \mp r_2)\sqrt{d^2 - b^2}}{d^2}. \tag{21}$$

Again the upper sign holds for the U-loop, the lower sign for the S-loop. The expression for $\sin \gamma$ can be expanded in powers of A after substituting b from Eq. (19). Then the resulting series for $\sin \gamma$ can be converted into a series for γ. Further, the difference $(\epsilon_1 - \sin \epsilon_1)$ can be expanded in powers of $\sin^2(\frac{1}{2}\epsilon_1)$ and therefrom expressed in terms of A by means of (10). The same procedure can be applied to the difference $(\epsilon_2 - \sin \epsilon_2)$. Thus finally, after substituting in the two equations (18) all the expanded terms discussed above, a series expansion of the film slack S in terms of A emerges. It can be written identically for both loop shapes if a new sign convention is adopted for the two drum radii. While so far these radii were treated as positive quantities, the following sign rule may now be introduced.

U-loop:

r_1 and r_2 positive, so that $r_1 r_2 > 0$

S-loop:

r_1 positive, r_2 negative, so that $r_1 r_2 < 0$

The final result is

$$S = \frac{A^3}{12}\left(\frac{1}{r_1^3} + \frac{1}{r_2^3}\right) - \frac{A^4}{8 s_t}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)^2 + \frac{A^5}{320}\left(\frac{1}{r_1^4} + \frac{1}{r_2^4}\right) - \frac{A^2 s_t}{r_1 r_2} \exp\left(-\frac{s_t}{A}\right) + \dots \tag{22}$$

It is seen that this series is not a true power series in A because exponential expressions appear in it. The latter are due to singularities of the elliptic integrals at that point $k = 1$, $\varphi = \pi/2$, around which the series expansion for S was required. Whether the exponential term is negligible in comparison to the highest power term given above must be decided in the particular practical application. Presumably in most motion picture applications it will be negligible. The case that the magnitude of the exponential term approaches that of the lower power terms may be considered as an indication

that the film loop is not flat enough for the limited number of series members in Eq. (22).

In order to establish a basis for the comparison of the above result with the earlier published paper,[2] the special case now is considered that the film slack S is to be measured between drum 1 and the inflection point of an S-loop. As the radius of curvature at the inflection point is infinite, one might try to derive the just mentioned special case from Eq. (22) by making r_2 infinite. However, according to Eq. (11S), $\cos \varphi_2$ would then equal zero and thus violate the condition (13a). It is therefore necessary to go back to the initial equations and to apply there the substitution $r_2 = \infty$. It can be shown that also for infinite values of r_2 the correct result is obtained from the series (22), if the vanishing exponential term is replaced by another exponential term, namely

$$+ \frac{A^2 s_i}{r_1^2} \exp\left(-\frac{2s_i}{A}\right).$$

Comparing now this result with Eq. (67) of Ref. 2, one finds that the latter does not contain exponential members. The reason is that the "loop equation (60)" of Ref. 2 is only an approximation. The first series term of the quoted Eq. (67) is correct, the second term is approximately correct as the "inflection distance D" of Ref. 2 is approximately equal to s_i. It further appears that no general simple additive rule exists between the total slack S and the partial amounts S_1 and S_2, measured from the inflection point to the two drums. Only with regard to the first approximation,

$$S \approx \frac{1}{12}\left(\frac{EI}{P}\right)^{1/3}\left(\frac{1}{r_1^3} + \frac{1}{r_2^3}\right), \quad (23)$$

does such an additive rule exist. It is remarkable that, in first approximation, S is independent of the drum separation d.

In order to obtain from Eq. (22) the length S, the film pull P must be known. As pointed out earlier, the designer of film drives is primarily concerned with the tangential component T of the film pull P because only this force T reflects in the torque N exerted on the drums. As it is seen from Fig. 1, the torque N_1 on drum 1, counted counterclockwise, is

$$N_1 = M_1 + T_1 r_1 = \frac{EI}{r_1} + T_1 r_1. \quad (24)$$

Using the parameter

$$t_1 = \sqrt{\frac{EI}{T_1}} = \frac{r_1}{\sqrt{\frac{N_1 r_1}{EI} - 1}} = \frac{A}{\sqrt{\cos \epsilon_1}}, \quad (25)$$

one can convert the series (22) into another series expanded in terms of t_1 so that, in conjunction with Eq. (25), for any torque N_1 the length S can be directly determined. The converted series reads

$$S = \frac{t_1^3}{12}\left(\frac{1}{r_1^3} + \frac{1}{r_2^3}\right) - \frac{t_1^4}{8 s_i}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)^2 - \frac{t_1^5}{320}\left(\frac{19}{r_1^4} + \frac{20}{r_1^2 r_2^2} - \frac{1}{r_2^4}\right) - \frac{t_1^2 s_i}{r_1 r_2} \exp\left(-\frac{s_i}{t_1}\right) + \ldots. \quad (26)$$

The coefficients of the first two series members are the same as those of the first two members of series (22). Thus as first approximation the simple formula (23) is valid again if the tangential force T is substituted for the film pull P.

Until now the film was treated as a homogeneous flexible rod which in the absence of external forces is perfectly straight. As to homogeneity, it must be said that the perforation holes cause a periodic variation of the bending stiffness, resulting in a loop curve which is slightly wavy. This variation, however, is very small and presumably of no importance with regard to the amount S of looped film, especially if a suitable average value is assumed for the bending stiffness. On the other hand, film curling, the second offender, may sometimes produce an appreciable effect. As far as longitudinal film curling is concerned, this effect can be taken into account in the theoretical relations derived above.

Suppose the natural radius of curvature of the curling film in the longitudinal direction is constant for the considered length of film and denoted by r_n, counted positive if the film tends to curl around drum 1. Since in this case the first of the two Eqs. (1) modifies to

$$M_1 = EI\left(\frac{1}{r_1} - \frac{1}{r_n}\right),$$

the relation (25) for the parameter t_1 changes to

$$t_1 = \frac{r_1}{\sqrt{\frac{N_1 r_1}{EI} + \frac{r_1}{r_n} - 1}}. \qquad (27)$$

The loop Eq. (4) remains unchanged. This can be visualized from its physical meaning, namely, being an equilibrium condition for the moments acting on the film. If a piece of film is considered between the contact point CP_1 and any other point of the loop, it is seen that the two opposing bending moments at the ends of this piece are proportional to the change of curvature which the film has undergone when being deformed from its natural state. The difference between these two bending moments is balanced by a force couple which originates from the relative parallel shift of the opposing force vectors P at the considered points (see Fig. 1). Since only the difference between the two bending moments enters the equilibrium condition, one need consider only the difference of the changes of curvature at the two points. But in this difference the original curvature of the curled film drops out as it was assumed constant over the whole length of film. Thus the loop Eq. (4) and all ensuing relations, including the final result (26), are independent of r_n. In other words, the effect of film curling reflects only in the value of the parameter t_1 as per Eq. (27). This value in connection with Eq. (26) yields the correct length of slack film.

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Auditory Perspective—A Study of the Biological Factors Related to Directional Hearing

By H. G. KOBRAK

The biological principles of auditory localization as related to stereosound reproduction are discussed. The human head carries two laterally-attached, biological sound receivers and the conduction of sound within these receivers, their position and the role of the skull in the sound field are also discussed. The attributes of the acoustic signal relevant to sound localization and the role of the central nervous system in the integration of binaural auditory stimulation are described. The factors of experience and training are stressed.

IN PRIMITIVE LIFE, the sense organ of hearing has to fulfill two basic functions. It has to warn the individual of approaching danger and must enable him to seek and to find the mate. In coping with the function as warning mechanism, it is absolutely essential that the individual not only be notified that a dangerous sound has occurred, but it is equally important that the direction from which the danger lurks be known simultaneously. The ability of directional hearing must therefore be considered a basic and important function of the ear.

All attempts to explain the directional abilities of the human ear assume that the hearing organ receives stimuli which vary with the position and distance of the source. The interpretation of certain physical cues, based on past experience, is the quintescence of directional hearing. The interpretation must give information on the distance of the sound source and its direction. In the presence of several sound sources, a spatial orientation in regard to the relative position of each source is accomplished. This spatial perception of different sound sources is called auditory perspective.

Attempts have been made to create an auditory perspective in an audience. The sensation of three-dimensionality of the sound in the listener has been called the stereophonic effect. It is natural that all experiments attempting the creation of stereophonic effects must be based on a thorough knowledge of auditory perspective.

Auditory perspective is based on, and accomplished by, a number of factors.

1. Physical factors, concerning the attributes of the acoustic signal.
2. Physiological factors, concerning the biological characteristics of the human ear as sound receiver.
3. Psychological factors concerning the interpretation of acoustic cues.

Presented on May 3, 1951, at the Society's Convention in New York, by Dr. H. G. Kobrak, Division of Otolaryngology, University of Chicago, 950 E. 59th St., Chicago, Ill.

4. Coordination with the information received by other sense organs.

If a sound comes from the side, as distinguished, say, by sight, most likely a short turn of the head will be made in order to face the sound source. The movement of the neck muscles as proprioceptive stimulus and the visual clue are combined and utilized in the spatial auditory perception. Among the psychological factors there is a most important one which is responsible for the creation of the stereophonic effect: the acoustic experience of the audience.

The individual will unknowingly compare his present auditory cues with similar past experiences.

How important experience is will be illustrated in Fig. 1. It is an example taken from stereovision, but it applies also to acoustic stereoperception.

Figure 1 shows three forms of plane geometry: a square and two rhomboids. Undoubtedly they are two-dimensional entities. If the three planes are put together in a certain way, most observers will perceive a three-dimensional entity, namely a cube. A person who never before saw a cube would not obtain the stereoeffect. Furthermore, it should be recognized that Fig. 1 gives not one, but two possible three-dimensional solutions. The sketch can represent a cube and also a half-open box with the left and lower sides missing. The vertical square, in such a case, appears to be farther away from the eye, while the two rhomboids appear to come toward the eye. The sketch was actually drawn for this stereoeffect. Observers visualize according to their experience. A cube is frequently encountered, while the other form would be rarely observed. Therefore, the majority will see a cube in Fig. 1.

Another comparison with the sense of vision seems in order. Stereovision is accomplished by the coordination and the integration of the perception of the two eyes. The mechanism by which the eye is able to render three-dimensional perception is considered well known.

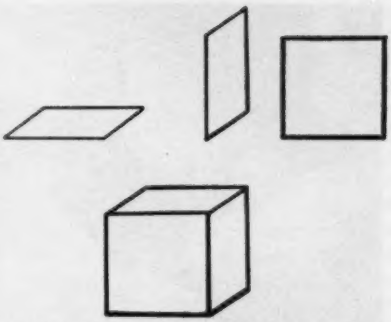

Fig. 1. The role of experience and probability in stereoperception.

The upper part of this sketch shows a square and two rhomboids. By placing these two-dimensional forms together, a stereoperception results. Most observers will see in the lower sketch a cube; a second stereoeffect (square away from eye) will be seen less frequently because a cube is an object which is more frequently encountered.

Since light travels in a straight line, the angle which the eyeball has to assume in order to face the source gives a clear definition of the direction. Since there will be a small difference in the angles which the right eye assumes, compared to those of the left eye, we have a simple geometrical problem: a base line of known dimension, i.e., the interpupillary distance and two angles. Elementary trigonometry will permit us to give direction and estimation of distance. (An important factor in distance estimation is familiarity with the objects. The size of the object should be known.)

The problems of auditory perspective are considerably more complicated because of the nature of the sound stimulus. Sound does not travel in a straight line nor does it produce sharp shadows. At least, this is true for the lower frequencies.

It must be assumed, therefore, that a simple trigonometric approach, as in stereovision, cannot solve the problems of auditory perspective. Some animals, however, utilize the position of the outer

Fig. 2. The human ear. Phase relation of the two cochlear windows.

Enlarged picture of the cochlea: the stirrup, st, the round window, rw, the promontory, P, and the facial nerve, F. Under normal conditions, the stirrup executes acoustic vibrations which in turn produce vibrations of the fluid column in the scalae vestibuli, sv, the basilar membrane and the scala tympani, s tym. The round window membrane acts as a "yielding area." Its phase is opposite to that of the stirrup. This normal phase relation is essential for normal directional hearing.

In patients with destroyed sound conduction system, sound impinges onto the two cochlear windows directly and the phase of the two windows is identical. Disturbance of directional hearing results.

ear for directional hearing much as the eyes are utilized in turning toward the visual source.

Some game animals have large outer ears which are movable in all directions. The larger size and the directional qualities of the pinna in these animals give a greater hearing sensitivity for faint sounds and better directional selectivity. It has been estimated that the ear of the deer is superior to that of the hunter by 8 db in hearing faint sounds.[1] In higher-order animals like apes, and also in man, the motility of the outer ear is no longer found. With the assumption of the upright position for locomotion and improved eye and brain function, there is apparently a shift to assign to the eyes and to the brain a greater part of the judgment of directional hearing. The superior development of the brain permits a more critical and correct interpretation of the acoustic environment.

When we study the auditory perspective today, we should not overlook this development within the animal kingdom. It shows that nature has not intended the ear to be the only judge in directional hearing. It is a coordinated interpretation of acoustic stimulation in conjunc-

tion with impressions obtained from other sense organs and integrated and judged by the centers of the central nervous system.

The human ear is a biological transducer which changes mechanical waves into nerve impulses. Naturally, any bodily structure which possesses mass and stiffness will execute forced vibrations under the influence of the acoustic signal. When sound impinges onto the ear, a number of middle and inner ear structures begin to oscillate as forced vibrations. However, some structures possess an especially favorable construction and, therefore, are more effective and economical in the conduction of sound energy. Experimental evidence has shown that the eardrum, with the three attached bones (hammer, anvil and stirrup), is the best and, therefore, most important sound conductor, while conduction through the bone of the skull and through the air of the middle ear is insignificant under normal conditions.

The normal process of sound conduction through the chain of small bones in the middle ear to the oval window of the cochlea is fundamentally an impedance-matching arrangement. The elastic medium in which man lives and through which the acoustic signals arrive is air. The inner ear is filled with fluid. The ossicular chain is an impedance-matching device which bridges the air-water boundary. The footplate of the stirrup, by its acoustic oscillations, sets the fluid of the inner ear into vibrations. It is a biological underwater sound source. The vibrating fluid volumes must be considered as mass displacements. The round window membrane (Fig. 2) constitutes a yielding spot. When the stirrup pushes inward, the round window membrane moves outward. On the other hand, when the stapes executes an outward motion, the round window moves inwardly.

An experimental method was worked out at the University of Chicago by which it was possible to visualize and to photograph these vibrations within the ear under controlled experimental conditions. [As a part of the Convention presentation a motion picture was shown by which the oscillations of the stirrup and the round window membrane were seen and the phase relation observed.] This normal phase relation is important for directional hearing. Békésy[3] has carried out interesting experiments on persons with diseased ears. Patients who have lost the eardrum and hammer and anvil, either by disease or by operation, have a different phase relation between oval and round window. In these cases the predominance of ossicular sound conduction is missing. Sound waves enter the middle ear and impinge on both windows with practically the same phase. Experiments show that these patients judge the direction of a sound source opposite to that of a person with normal hearing. In cases of eardrum perforations, an artificial eardrum can be inserted which occludes the direct access of sound waves to the middle ear cavity. The directional hearing then changes again to normalcy. [The therapeutic procedure of the surgeon which brings about this reversal of directional hearing was also demonstrated by a motion picture.]

When sound impinges onto the head of an observer, a certain percentage of the total sound energy will be conducted through the bones of the skull. This pathway of sound leads directly to the inner ear without utilizing the chain of middle ear ossicles (Fig. 3). The otic capsule undergoes periodic contractions and rarefactions which produce vibrations in the inner ear fluids. The oscillations of the introcochlear fluid produce a hearing sensation which is identical to that produced by sound conduction through the ossicles. There is, however, one important difference. The direct bone conduction is a conveyance through a solid medium, therefore, a fast phenomenon. The sound conduction through eardrum and ossicular chain is measur-

Fig. 3. The human ear; concept of bone conduction; a cross section of the middle ear, M, and the cochlea, C.

The two bony canals (scalae) which are winding in 2½ coils around the axis are shown. During the process of hearing, some sound energy travels through the bone and produces waves of compressions and rarefactions of the bony capsule. This is called bone conduction (indicated by single arrows). Normally, there is a phase difference between bone-conducted sound and ossicular sound conduction. However, the influence of direct bone conduction is small in normal ears. The impulses set up in the nerve are carried through the nerve fibers in the axis of the cochlea (double arrow) and go into the central nervous system through the acoustic nerve (triple arrow).

ably slower.* Therefore, under normal conditions there is a phase difference between the direct bone conduction and the ossicular sound conduction. This phase difference has been demonstrated experimentally by Krainz.[3] Normally, the percentage of sound energy traveling through the skull bones to the inner ear is negligible compared to the conduction through the middle ear chain.[4]

However, a person wearing a hearing aid utilizes direct tissue-and-bone conduction to an appreciable extent. The phase difference between the two stimuli may be important enough to produce disturbance of the auditory perspective. Due to the fact, however, that man utilizes his past experience and his visual and tactile cues to such a large extent, this disturbance is easily checked and counterbalanced.

For natural and correct judgment of sound location both ears are necessary. The destruction of one ear creates errors

* The time element in ossicular sound conduction can be demonstrated in motion picture records.

in the judgment of sound direction. This can be demonstrated easily and has been known for a long time.

If one plugs an ear with cotton, apparent direction of the sound source may differ considerably from the true one. The number of persons suffering from various degrees of hearing impairment is great. It is very difficult to give exact figures: 1,500,000 to 3,000,000 children in the United States are estimated to suffer from defective hearing. Extensive surveys among adults, comparable to those of school children, are more difficult to make. One can say that roughly 5% of the future adult citizens of the nation have hearing losses.

Several factors of binaural hearing have been investigated as to their importance in sound localization.

There are several principal ways in which the sound signal reaching the right ear may differ from the sound signal incident to the left ear. The intensity of the stimulus, its phase, its wave composition and its time of arrival may differ.

An intensity difference, provided it is great enough, causes a displacement of localization toward the ear receiving the greater stimulus. This phenomenon is more important in high tones. The head is a small obstacle for low tones and its interference, therefore, negligible. However, for frequencies above 5000 cycles/sec the difference in loudness level between the two ears may be great. Steinberg and Snow[5] measured a difference of 30 db for 10,000 cycles/sec for an azimuth of 90°. The difference may be even greater for other azimuths.[6] When the sound stimulus is a complex signal, such as music or speech, then some of the high-frequency components are lost to the ear on the far side of the head and a considerable difference distortion in the composition of the signal results. Due to the shadow effect for high tones, the two auricles cast a definite shadow for tones coming from the rear.

When two tones, differing in phase, are conducted to the ears, the listener will

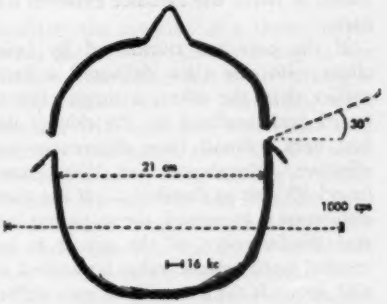

Fig. 4. The physical properties of the skull and its importance on directional hearing. Human skull seen from above.

The sketch tries to demonstrate the size of the average human head in relation to the wavelength for airborne tones of 1000 cycle/sec and 16,000 cycle/sec. It is apparent from this sketch that low tones have a wavelength which is large in comparison to the skull. The diameter of the head equals roughly one-half of the wavelength of 800 cycle/sec. High frequencies above 5000 are perceived best when entering from an angle 30° forward. This is due to the shape and position of the auricle.

The velocity of sound in air being 330 m/sec, it takes 0.0006 sec for the sound to travel a distance equal to the diameter of the head. This is the maximum time difference which can occur when a single sound falls on the ears.

localize the sound source toward the side of the leading phase. A sound wave coming from the side will reach the closer ear before it reaches the ear on the far side of the head. It can readily be seen (Fig. 4) that a situation may arise in which the difference in the length of the path between the two ears is greater than half of the wavelength of sound. Under such a condition, the location of the sound source on either side of the head may give the same phase difference at the two ears. Therefore, for high frequencies, localization based on phase differences becomes unreliable. The critical frequency is about 800. The wavelength of 800 cycle/sec in air is about 40 cm,

which is twice the distance between the ears.

If the ears are stimulated by brief clicks with one click delivered a little earlier than the other, a single click is heard and localized on the side of the first click. Small time differences are effective. Hornbostel and Wertheimer found 30 μsec as threshold. If the time difference is increased, the apparent lateral displacement of the sound is increased until critical value is reached at 630 μsec. If the time of incidence differs more than this value, two distinct tones are heard, one on one side and one on the other. If a source of a continuous sound is near the head of an observer, the amplitude of the signal at the near ear is greater than that of the far ear. Apparently it is possible for the ear to utilize the amplitude ratio for estimation of the distance of the source. The results are rather unstable for different observers.

If a listener is permitted to move his head while determining the direction of the sound source, his ability to judge is greatly enhanced. Most people know this instinctively and move their heads while listening. If a sound comes from the front, it will appear to come from the right side when the head is turned to the left. The opposite is true when the head is turned to the right. The sound source will then appear to be on the left side. The importance of small head movements for directional sound perception can hardly be overemphasized. Some physiologists even go as far as to "explain" the juxtaposition of the cochlea and the vestibular organ in the inner ear by the coordinated body movements in relation to sound sources.

For a conscious sensation of directional hearing, it is necessary that the central nervous system (Fig. 5) receive and utilize the small differences of stimulation between the right and left ear.

Stereophonic Effect

When a listener is facing an orchestra, he is exposed to a complex sound stimulus which originates not from a pointlike sound source but from an area. The spatial relation of the various instruments can be sensed by the listener. In other words, from the influx of the various sounds he can pick out the direction from which the sound of each group of instruments comes. This is the stereophonic effect of multiple sources of sound.

Important experiments on the reproduction of spatial relation of multiple sound sources were carried out by members of the Bell Telephone Laboratories during the last 20 years.[4]

Ideally, an infinite number of microphones and loudspeakers would be needed to obtain perfect reproduction.

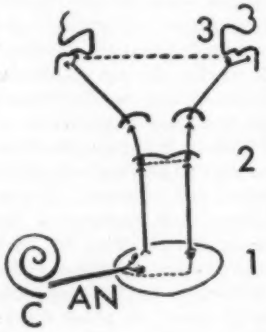

Fig. 5. Sketch of the auditory pathways in the central nervous system.

A highly simplified diagram. From the cochlea, C, of the inner ear an acoustic nerve, AN, leads to the medulla oblongata, 1. There the nerve fibers make contact with a new unit of the auditory system. A part of the fibers cross to the opposite side, the rest ascends to the next higher relay center located in the inferior collicus, 2. There another interruption and another crossing of some fibers take place. After another relay station in the medial geniculate body is passed, the auditory pathway reaches the auditory cortex, 3.

The diagram demonstrates the anatomical locations where impulses from one ear are partially transmitted to the opposite. The interplay of messages from right and left ear is interpreted by the high acoustic nerve centers and integrated into an auditory perspective. There are at least three levels known (1, 2, 3) within the central nervous system where impulses cross to the opposite side.

Experiments have shown, however, that only three, perhaps even only two microphone–loudspeaker combinations will give satisfactory auditory perspective. In the experiments of Steinberg and Snow, microphones were set on the stage and the corresponding loudspeakers were placed before an audience. The loudspeakers were placed behind a curtain. A group of observers were asked to judge from which point behind the curtain the signals appeared to originate. With three-channel reproduction, there was a good correspondence between the caller's actual position on the pickup stage and his apparent position on the virtual stage. Both attributes of forward and back as well as right and left differences were fairly well identified.

When the three-channel reproduction was reduced to a two-channel reproduction, the observers reported that the stage appeared less deep, but perhaps broader. Steinberg and Snow concluded that the loudness difference at the two ears of the observer is responsible for the accurate judgment of the angular localization.

Conclusions

The engineer who attempts to create auditory perspective in an audience should have in mind the auditory experience of his audience. If we interpret the facts of comparative physiology correctly, we come to the conclusion that the development in the animal kingdom led from a large mobile directional sound receiver (as found in fleeing herbivores) to a smaller and immobile, perhaps even rudimentary, pinna of the primates and man. Parallel to this transformation of the outer ear there is the assumption of erect posture and improvement of brain function. This means that man uses visual clues to a considerable extent. In addition, the brain will act to interpret the signals by integrating the auditory messages and comparing them with nonaural stimuli. Previous experience will facilitate the creation of a three-dimensional aspect. If there is a dog in the corner of the room and some barking is being heard from this direction, most listeners will combine the visual and auditory impression, but if there is some meowing coming from the dog's mouth, the alert listener will search around for another sound source, because his experience tells him that the meow could not have come from the dog's mouth.

Movements of the head are very important for directional hearing. Most people will make small turns of the head unknowingly while listening to a hidden sound source. If the sound source is visible, the listener will turn his head until he faces the sound source.

Normal hearing ability in both ears is the prerequisite for natural auditory perspective. One-sided deafness produces errors of sound localization. The number of persons suffering from various degrees of hearing impairment is great. However, since man utilizes visual perception to a great extent, aural deficiencies can, in most cases, be overcome without resulting in any serious auditory disorientation.

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Color Television—U.S.A. Standard

By P. C. GOLDMARK, J. W. CHRISTENSEN and J. J. REEVES

This paper is divided into four sections. The first deals with the actual standards as established by the Federal Communications Commission and discusses their colorimetric significance. Section II discusses the design and performance of typical commercial color-television receivers. Section III will be of special interest to the broadcaster as it describes the conversion of existing black-and-white studio equipment for color-television use. Some data on studio installation and lighting are also supplied. Section IV deals with nonbroadcast uses of color television and describes industrial color-television equipment known as Vericolor.

I. Color-Television Standards

MOST OF THE fundamental data and early developmental stages of the field-sequential color-television system have been available to the engineering profession, partly from earlier publications (also, see the paper immediately following in this JOURNAL) and partly from material presented at the FCC hearing.[1-3] Now that color television has attained the status of commercial operation, it seems advisable to fashion this paper in such a way that it is most useful to the studio and receiving-equipment engineer.

It is appropriate to begin with a recital of the official FCC color-television standards as they appeared in the *Federal Register* and to follow this with a brief discussion of their significance from a colorimetric point of view.

It is ordered, That effective the 20th day of November, 1950, the Commission's "Standards of Good Engineering Practice Concerning Television Broadcast Stations" are amended in the following respects:

(I) Paragraphs 5, 6, 7 and 8 of Section 1B entitled "Visual Transmitter" are revised to read as follows:

5. Color transmission. The term "color transmission" means the transmission of color television signals which can be reproduced with different values of hue, saturation and luminance.

6. Field. The term "field" means scanning through the picture area once in the chosen scanning pattern and in a single color. In the line-interlaced scanning

A contribution submitted September 4, 1951, by Peter C. Goldmark, John W. Christensen and James J. Reeves, Laboratories Division, Columbia Broadcasting System, Inc., 485 Madison Ave., New York 22, N.Y. This paper is being published simultaneously in the *Proceedings of the I.R.E.* This paper is, in parts, a development from the one given Oct. 16, 1950, at the Society's Convention at Lake Placid, N. Y.

[1] P. C. Goldmark, J. N. Dyer, E. R. Piore and J. M. Hollywood, "Color television—Pt. I," *Proc. I.R.E.*, vol. 30, pp. 162–182, Apr. 1942.

[2] P. C. Goldmark, E. R. Piore, J. M. Hollywood, T. H. Chambers and J. J. Reeves, "Color television—Pt. II," *Proc. I.R.E.*, vol. 31, pp. 465–478, Sept., 1943.

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pattern of two to one, it means the scanning of the alternate lines of the picture area once in a single color.

7. Frame. The term "frame" means scanning all of the picture area once in a single color. In the line-interlaced scanning pattern of two to one, a frame consists of two fields.

8. (a). Color field. The term "color field" means scanning through the picture area once in the chosen scanning pattern and in each of the primary colors. In the line-interlaced scanning pattern of two to one, it means the scanning of the alternate lines of the picture area once in each of the primary colors.

(*b*). *Color frame.* The term "color frame" means scanning all of the picture area once in each of the primary colors. In the line interlaced scanning pattern of two to one, a color frame consists of two color fields.

(II) Paragraphs 5, 6 and 13 of Section 2A entitled "Transmission Standards and Changes or Modifications Thereof" are revised to read as follows:

5. For monochrome transmission the number of scanning lines per frame shall be 525, interlaced two to one in successive fields. The frame frequency shall be 30, the field frequency 60, and the line frequency 15,750 per second.

6. For color transmission the number of scanning lines per frame shall be 405, interlaced two to one in successive fields of the same color. The frame frequency shall be 72, the field frequency 144, the color frame frequency 24, the color field frequency 48, and the line frequency 29,160 per second.

13. The level at maximum luminance shall be 15% or less of the peak carrier level.

(III) The following new paragraphs 19 and 20 are added to Section 2A:

19. The color sequence for color transmission shall be repeated in the order red, blue, green in successive fields.

20. The transmitter color characteristics for color transmission shall be such as to reproduce the transmitted colors as correctly as the state of the art will permit on a receiver having the following trichromatic coefficients, based on the standardized color triangle of the International Commission on Illumination:

Red	*Blue*	*Green*
$x = 0.674$	$x = 0.122$	$x = 0.227$
$y = 0.326$	$y = 0.142$	$y = 0.694$

(IV) New "Appendix I" attached hereto entitled "Television Synchronizing Waveform" is substituted for "Appendix I" of the "Standards of Good Engineering Practice Concerning Television Broadcast Stations."

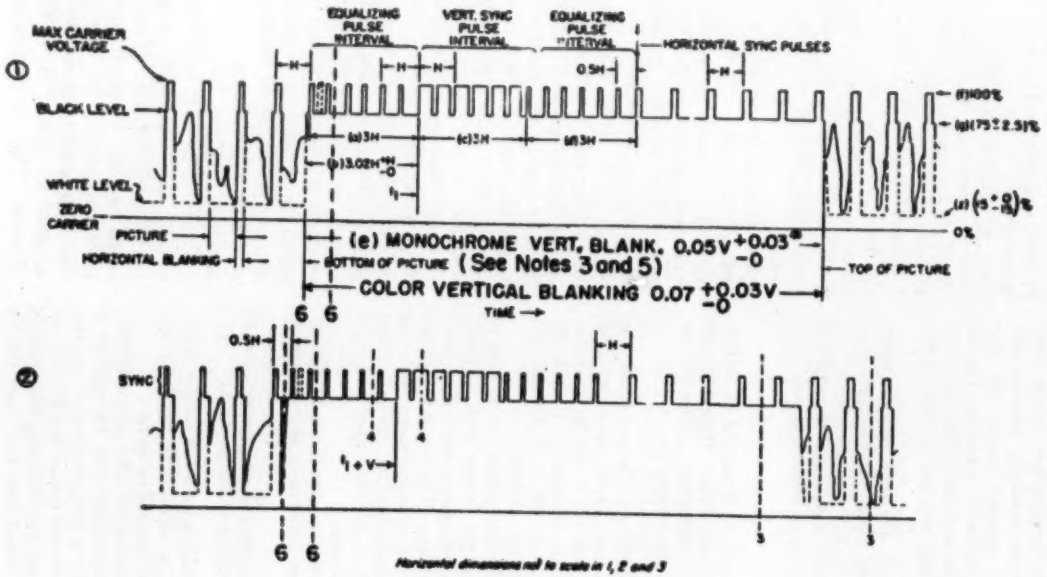
(Secs. 4, 303, 48 Stat. 1066, as amended, 1082 as amended; 47 U.S.C. and Sup. 154, 303, interprets or applies Sec. 301, 48 Stat. 1081; 47 U.S.C. 301)

Released: October 11, 1950.

Figure 1 shows the television synchronizing waveforms which combine both the black-and-white and the color waveshapes as well as their numerical values.

Referring to paragraph 20 of the preceding standards, dealing with the transmitter color characteristics, it is important to realize their real significance. The receiver primaries *E* to which the standards refer are shown in Fig. 2. The coordinates on the ICI color diagram correspond to those listed in paragraph 20. These primaries *E* satisfy certain performance conditions for specific types of color receivers. The ratios of the luminosities of these primaries are green to red to blue as 2.9 to 1.8 to 1. Because of the favorable ratios, these primaries at the receiver will permit a high flicker threshold illumination. Thus, if receiver illumination as high as 24 ft-L (foot-Lamberts) is required and a color disk is used, these primaries *E* are recommended. The theoretical maximum color gamut possible with these primaries is more than adequate.

Calculations and experiments, comparing the maximum possible color fidelity with primaries *E* using only the major positive lobes of the transmitter color curves (Fig. 3), have shown that the color fidelity obtainable is at least as good as, if not better than, Kodachrome. This is particularly true if



Legend:

1 H = Time from start of one line to start of next line

2 V = Time from start of one field to start of next field

3 Leading and trailing edges of vertical blanking should be complete in less than 0.1H

4 Leading and trailing slopes of horizontal blanking must be steep enough to preserve minimum and maximum values of (x + y) and (i) under all conditions of picture content

5 Dimensions marked with asterisk indicate that tolerances given are permitted only for long time variations and not for successive cycles

6 Equalizing pulse area shall be between 0.45 and 0.5 of area of a horizontal sync pulse

7 Color pulse area shall be between 0.45 and 0.5 of the area of a horizontal sync pulse

8 Refer to text for further explanations and tolerances

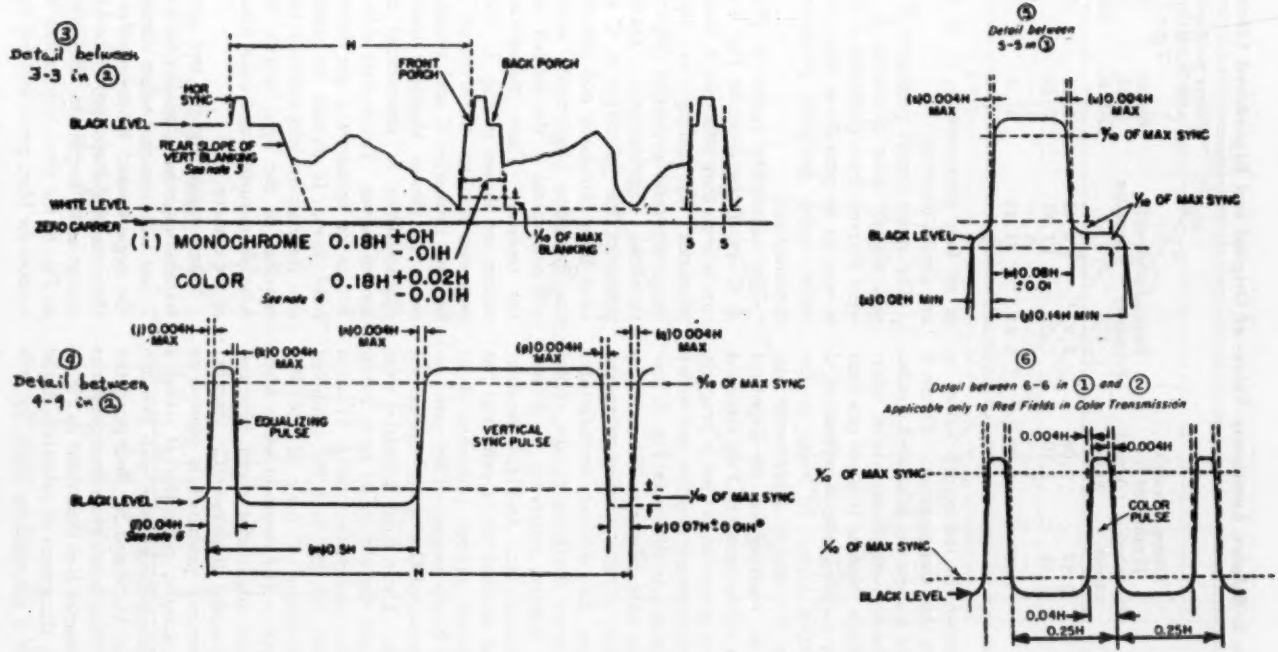


Fig. 1. Television synchronizing waveforms.

Table I. Relative Luminosity Values of Original and Reproduced Colors

Wratten filter No.	Filters through Illuminant C		Reproduced with		Filters photographed with Kodachrome Type 5	
	Published values	Actual values	Primaries C	Primaries A	Before (with 3200 K)	After (with 3200 K)
13	2.57	2.06	2.97	2.42	1.56	0.46
22	2.54	2.10	2.25	1.81	2.30	1.74
32	1.—	1.—	1.—	1.—	1.—	1.—
38	3.12	2.39	1.61	1.43	1.78	0.96

the distortion in luminosity values is also taken into consideration. Figure 4 and Table I show the tabulated results.

With the field-sequential system, when using a single camera, it is not practical to employ masking; that is, utilization of the negative lobes. In view of the results of the fidelity experiments just referred to, masking can be dispensed with. It will be shown that the standard transmitter primaries as used in practice, namely, without the negative and minor positive lobes, as shown in Fig. 5, can satisfy not only primaries *E* but also a wide variety of other receiver primaries. This gives the receiver manufacturer the necessary flexibility in the choice of color fidelity, resistance to flicker, light efficiency, etc. In Fig. 4 the color fidelity of another set of primaries has been plotted against primaries *A* as well as Kodachrome. They are receiver primaries *C* and are represented in Fig. 6. These color primaries were theoretically derived by an early industrial color committee, using Wratten filters Nos. 47, 58 and 25 combined with Illuminant *C* (one of the ICI illuminants). The resultant white when using equal amplitudes of red, blue and green is again Illuminant *C*. Another set of receiver primaries is plotted in Fig. 6, namely, primaries *D* using a specific phosphor mixture with Wratten filters Nos. 47, 58 and 26. Both primaries *D* and *C* show better blues than primaries *A* or primaries *E* as illustrated in Fig. 2; however, the greens of primaries *A* and primaries *E* are superior while the reds of all four primaries, *A*, *C*, *D* and *E* are almost identical.

The more recent primaries *E* differ only slightly from primaries *A*. They were derived from primaries *A* in such a way as to provide a more suitable white, using available phosphor-filter combinations.

The luminosity ratios of primaries *A*, *C* and *D* are given in Fig. 6 and it can be seen that primaries *A* (similar to primaries *E*) belong to the low luminosity-ratio primaries (high flicker threshold illumination). Transmitter primaries for primaries *A*, *C* and *D* have been calculated and plotted with the condition that equal amplitudes will correspond to the desired white at the receiver. These transmitter primaries are shown in Fig. 7. Actually, only two families of curves are shown because primaries *C* and primaries *D* result in almost identical transmitter characteristics as represented by the broken curves. Transmitter color sensitivities for primaries *A* are shown with solid lines. It should be understood that these sensitivities combine the color response of the light source, camera-tube photo-surface and color filters used at the camera.

When examining the two groups of transmitter color characteristics in Fig. 7, one will note that when disregarding the negative and minor positive lobes, the remaining shapes are almost identical except as to amplitude. Referring now to Fig. 5, the three transmitter characteristics for blue, green and red represent

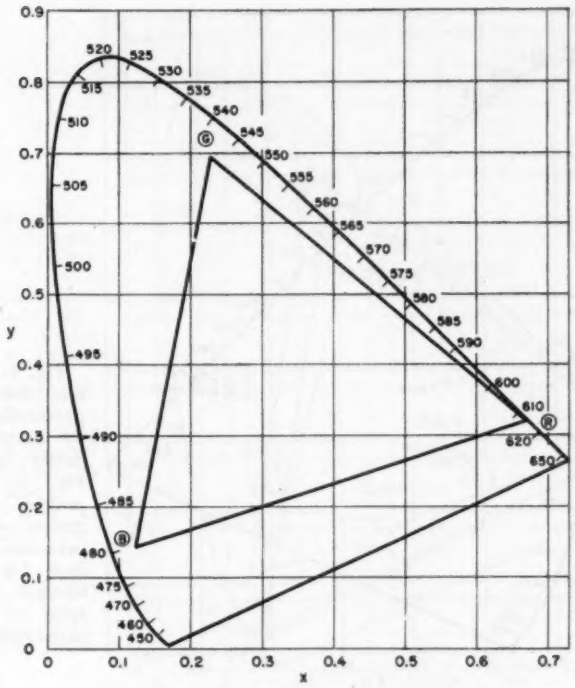


Fig. 2. Color triangle for receiver primaries *E*.

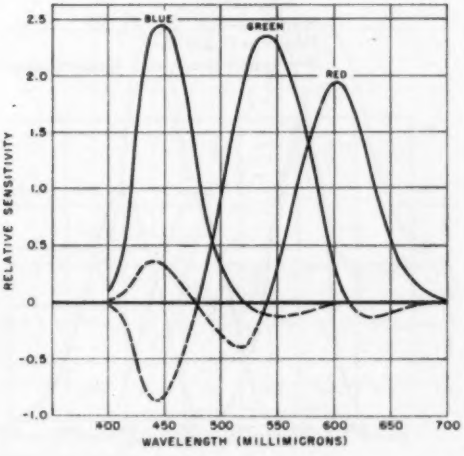


Fig. 3. Theoretical (ideal) spectral sensitivities of the transmitter based upon receiver primaries *E*. Note—White to be reproduced by equal voltages of the three primaries.

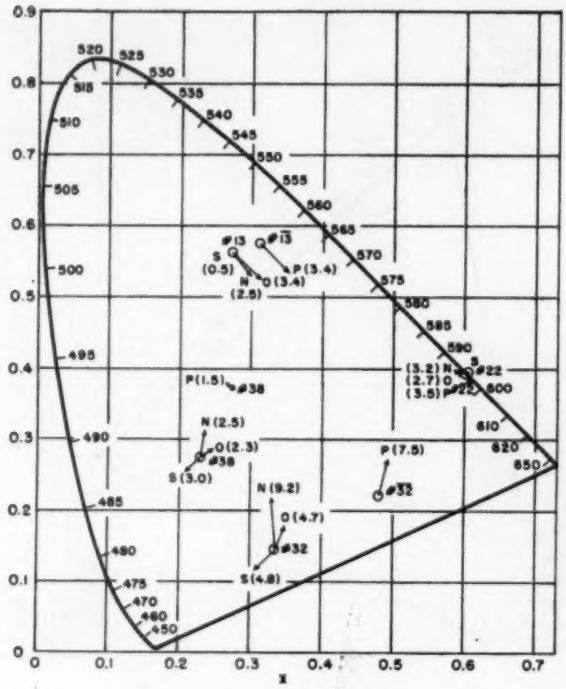


Fig. 4. Comparative fidelity of reproduction of colors by means of transmitter primaries of Fig. 3 (using only positive lobes) together with receiver primaries *C* and *A*, and type *B* Kodachrome. Note—Primaries *A* similar to primaries *E*.

Legend:
S = Published filter values
O = Reproduced with primaries *C*
N = Reproduced with primaries *A*
Numbers in brackets indicate approximate discernible color differences
Numbers—$\overline{13}$, $\overline{22}$, $\overline{32}$, $\overline{38}$
Filters at 3,200 K
P—Reproduced with Kodachrome type *B* and 3,200 K

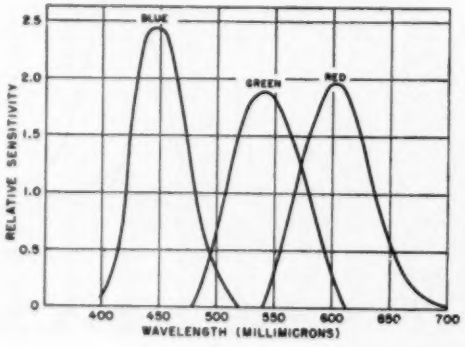


Fig. 5. Standard transmitter color primaries, neglecting minor lobes and adjusted to produce equal signal amplitudes for red, blue and green (based upon receiver primaries *E*).

Legend:
A—Low flicker synthetic primaries, White = Illuminant *C*
C—Color Committee Primaries: #47, 58, 25 Kodak filters + Illuminant *C*
White = Illuminant *C*
D—(dotted line) CBS 2-phosphor with #47, 58, 26 Kodak filters
Triangle *A* = γ_b: γ_r:γ_g = 1:1.5: 2.4
Triangle *C* = γ_b: γ_r:γ_g = 1:4.3: 12.3
Triangle *D* = γ_b: γ_r:γ_g = 1:4.9: 13.4.

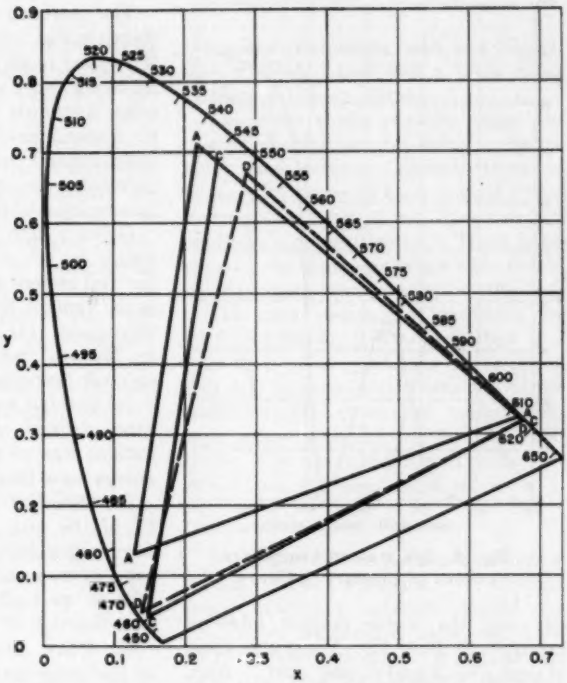


Fig. 6. Comparative color gamuts of receiver primaries *A*, *C* and *D*.

Legend:
I. Solid line = ideal transmitter color sensitivities for use with primaries *A*, reproducing white (Illuminant *C*)
II. Broken line = ideal transmitter color sensitivities for use with primaries *C*, reproducing white (Illuminant *C*)
Note—White to be reproduced by equal-signal voltages of the three primaries.

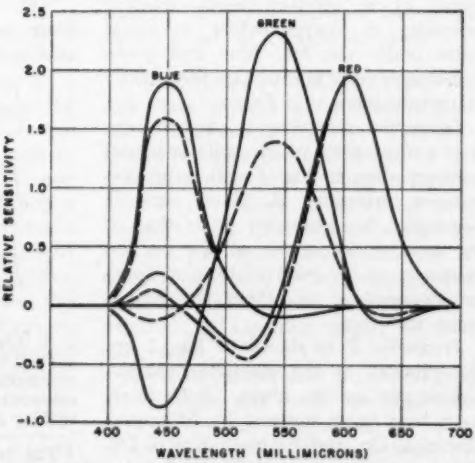


Fig. 7. Theoretical (ideal) spectral sensitivities of the transmitter based upon receiver primaries *A* and *C*.

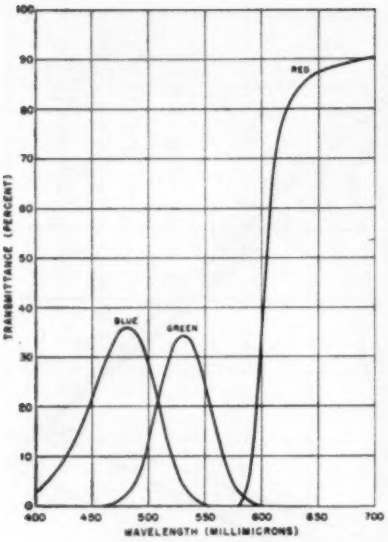


Fig. 8. Spectral transmittance curves of primary *E* filters.

not only the major positive lobes of primaries *E* from Fig. 3 but also those of primaries *A* and *C*, and thus *D*, from Fig. 7. The electrical amplitudes required to obtain the proper value of white at a receiver using receiver primaries *E*, corresponding to equal areas under the red, blue and green transmitter color sensitivities, are already taken into account in Fig. 5.

From the foregoing it can be seen that a transmitter which radiates signals corresponding to Fig. 5 will satisfy the receiver primaries *A*, *B*, *C* and *E*. Naturally, for primaries other than *E* the relative intensities of the various primaries at the receiver have to be so proportioned as to obtain the desired value for white.

Primaries *E* as shown in Fig. 2 are the product of the phosphor characteristic and specific filters. Such filters have been manufactured by Monsanto Chemical Co. and Eastman Kodak Co. in large acetate sheets. Figure 8 shows the typical transmittance curves.

The universal transmittance curves as shown in Fig. 5 require certain tolerances if they are to be used as standard. The following is an attempt to interpret the color standards in such a fashion that the transmitter characteristics are specifically defined, while at the same time permitting the utmost flexibility for the color-television receiver designer.

Given a light source illuminating the scene to be televised and having a spectral energy distribution *E*, where *E* is the radiant flux per unit wavelength throughout the visible spectrum (400 to 700 $m\mu$ (millimicron)), the overall spectral response comprises:

(a) Spectral sensitivity *S* of the camera tube, defined as its response to unit radiant flux of spectrally homogeneous energy as a function of wavelength,

(b) Spectral transmittances, *R*, *B*, *G*, of the red, blue and green color filters; spectral transmittances being the ratio of transmitted to incident radiant flux of spectrally homogeneous energy as a function of wavelength,

(c) Color amplitude factors *r*, *b*, *g*, of the color mixer, defined as the respective ratios of the outgoing and incoming individual color signals.

The camera sensitivity, the color filters and the color amplitude factors shall satisfy the following four conditions:

1. $\int_{550}^{660} ESRd\lambda \Big/ \int_{400}^{700} ESRd\lambda$ be not less than 0.90,
2. $\int_{410}^{500} ESBd\lambda \Big/ \int_{400}^{700} ESBd\lambda$ be not less than 0.90,
3. $\int_{490}^{600} ESGd\lambda \Big/ \int_{400}^{700} ESGd\lambda$ be not less than 0.90,
4. The color amplitude factors *r*, *b*, *g*, shall be adjusted so that the color signals, corresponding to a white test area* illuminated by the light source *E*, are equal within $\pm 5\%$.

* The white area of the test chart shall have a spectral reflectance substantially constant, independent of wavelength.

II. Commercial Color-Television Receivers

IT IS COMMON KNOWLEDGE that methods used by any color-television system for presentation of a color picture at the receiver may be used with the field-sequential system, while the converse is not true. Several of these methods are illustrated in Fig. 9. The majority are unsatisfactory for home use because of one or more of the following undesirable features: (1) difficulty of maintaining optical registration, (2) difficulty of maintaining electrical registration, (3) narrow viewing angle, (4) high cost, and (5) insufficient highlight brightness. Table II shows the undesirable features associated with each method.

Table II

Method (From Fig. 9)	Undesirable Features 1	2	3	4	5
a	X	X	X	X	
b	X	X		X	X
c	X	X		X	X
d	X	X			X
e					X
f					X
g					
h					
i		?		?	

The direct-view color tube will likely offer a convenient method, when developed to a commercial product at a reasonable price. Of the remaining tabulated methods, at present only the last three yield sharp color pictures usable in the home, and only the last two are capable of generating bright and sharp enough pictures for suitable home viewing in a normally lighted room. Both of these employ direct view with standard tubes; one uses the color disk and the other, the color drum.

With proper arrangement of disk and raster, a color disk need be only slightly larger than twice the tube diameter. For home use disks larger than 27 in. (12½-in. tube, enlarged to 16-in. picture) have not been employed. The arrangement most frequently used is a 22½-in. disk in combination with a 10-in. tube, yielding a 12½-in. picture.

The color drum provides large unmagnified color pictures within a reasonably sized cabinet. Several types of drum color receivers built around 17-in. rectangular tubes have demonstrated excellent picture qualities. There is no reason why 20-in. or larger direct-view color pictures cannot easily be obtained.

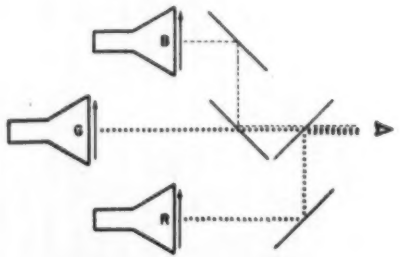
The color drum, first employed by CBS in 1940–41, will be described at a later date. The remainder of this paper will deal in some detail with two of the most recently developed commercial-type receivers employing the color disk. These are the combination color receiver and the slave color receiver.

Combination Color Receiver

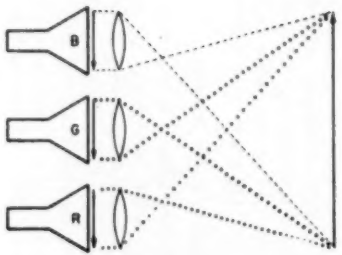
With the advent of standard commercial color television, a modern home television receiver should be capable of receiving equally well both monochrome and color. It should also have the ease of operation presently associated with monochrome receivers. The combination receiver here described satisfies these requirements and is designed to sell at a moderate price.

Physical Characteristics. The dual color disk drive used in the combination receiver is shown in Fig. 10. The main chassis is shown in Figs. 11 and 12 and a detailed schematic is given in Fig. 13. Including rectifiers, 23 tubes are used. Except for the dual-frequency scanning and the disk drive mechanism, the receiver is essentially the same as a standard monochrome receiver; discussion will therefore be confined largely to these differences.

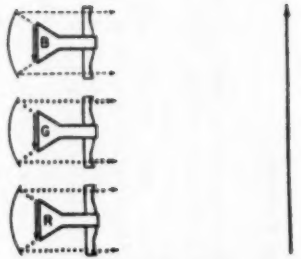
A 10FP4 picture tube is used for both monochrome and color. In both cases a 12½-in. picture is obtained by means of an oil-filled lens fastened integrally with the front of the cabinet. In the



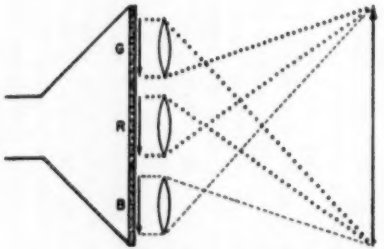
a) THREE TUBE-DIRECT VIEW
DICHROIC OR SEMI-SILVERED MIRRORS



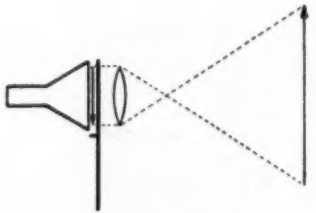
b) THREE TUBE - PROJECTION
REFRACTIVE OPTICS



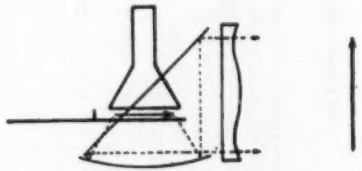
c) THREE TUBE - PROJECTION
SCHMIDT OPTICS



d) THREE RASTER TUBE-PROJECTION
REFRACTIVE OPTICS

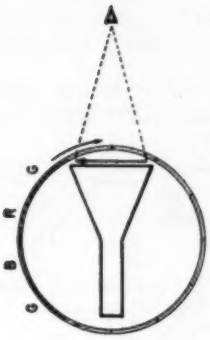


e) STANDARD TUBE-PROJECTION
COLOR DISC-REFRACTIVE OPTICS



f) STANDARD TUBE - PROJECTION
COLOR DISC-FOLDED SCHMIDT OPTICS

i) TRI-COLOR TUBE DIRECT VIEW



h) STANDARD TUBE - DIRECT VIEW COLOR DRUM

g) STANDARD TUBE - DIRECT VIEW COLOR DISC

Fig. 9. Color television picture presentation methods.

dual disk arrangement only one-half of each disk is covered with filters, the other one-half being transparent. This permits the disks to be relatively phased so as to provide between the tube and the observer continuous filters for color operation or, when stopped, only clear sections for monochrome operation. The disk assembly rotates between the tube face and the back of the lens.

In this set, for the sake of economy, the color-pulse separator is omitted and the color disk is synchronized from the vertical pulses. Since these pulses contain no color information, a color-phasing button on the front panel is provided (which has to be pressed no more than twice) to obtain the correct colors. In other units, containing the color-pulse separator, this color-phase button, of course, is not required.

A front panel color-monochrome switch permits manual selection of either of the two standards. When this switch is thrown to monochrome, the following takes place automatically: the scanning is changed to the monochrome rates; the dual disk is stopped with the clear disk sections superimposed; and the clear sections are rotated to a position over the tube face where no filters are visible.

Color-Disk Drive Mechanism. An important requirement for a color-disk drive mechanism and associated circuits is to maintain accurate disk phasing even when operating under changing temperatures, adverse conditions of varying line voltages and frequencies, and variable signal inputs. Further requirements are rapid acceleration of the disk to synchronism upon the application of power and short disk pull-in time, i.e., the time required to synchronize a disk after selecting a particular station. Moreover, electrical interference should be absent and weight, size, cost and mechanical noise should be a minimum.

The combination receiver disk drive mechanism shown in Fig. 10 satisfies

these requirements. Proper phase within ±2° over the normal range of operating temperatures is maintained with line voltages between 105 and 125 v and with line frequencies between 59.5 and 60.5 cycles/sec. The unit generates no electrical interference, has no rubbing contacts, and operates with a minimum of mechanical noise and vibration. It is designed to operate with a standard motor, a toothed rubber-fabric belt drive, and other components relatively easy to obtain.

As shown in Fig. 10 the dual disk assembly, generator, brake, and resiliently mounted induction motor are all fastened to a supporting baffle. Also mounted on the back of the baffle is the kinescope supporting structure. The disk housing is fastened to the front of the baffle by twist-lock screws. This housing completely encloses the disk in a fairly airtight space. Such an enclosure is important in order to keep disk driving power to a minimum and to retard the accumulation of dust on the disk and picture tube face.

The motor is a standard four pole capacitor induction type with the following operating characteristics: It delivers 23 in.-oz. torque at 1748 rpm with 80 to 85 v rms input at 60 cycle/sec. It is also capable of delivering the above torque at 1764 rpm with approximately 90 to 95 v input at 60 cycle/sec. This latter condition corresponds to operation at 1748 rpm at 59.5 cycle/sec. A centrifugal switch is provided internally which opens at approximately 1700 rpm and closes at approximately 1600–1650 rpm; its purpose will be described later.

The motor drives the disk shaft by means of a rubberized-fabric toothed

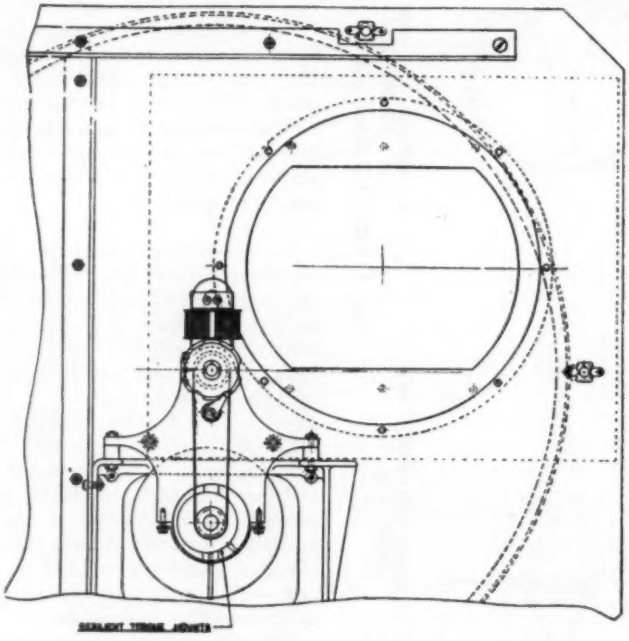
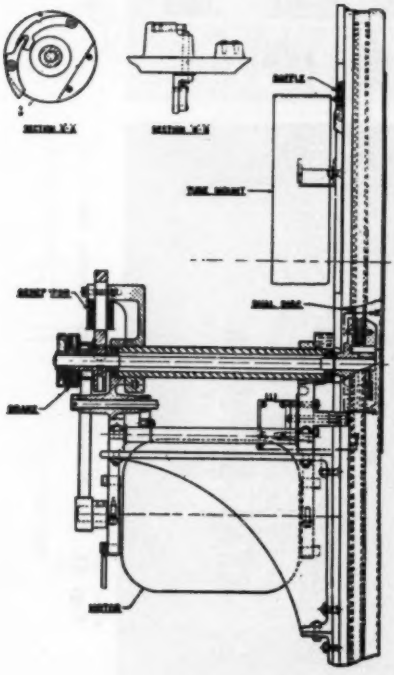


Fig. 10. Dual color-disk drive (cont'd. on next page).

timing belt, which maintains a constant speed ratio of 17/14 between the motor and the disk. With the disk rotating at 1440 rpm the motor rotates at 1748$\frac{4}{7}$ rpm.

The front color disk is fastened solidly to the disk drive shaft, while the back disk floats on the shaft and is free to rotate back and forth with respect to the front disk through approximately $\frac{1}{3}$ revolution. A centrifugally operated catch mounted on the back disk, as shown in section A-A Fig. 10, prevents it from rotating backward beyond a predetermined point. At this point the catch actuates a microswitch whose function will be described later.

When the disks are rotating rapidly forward the centrifugal catch withdraws and is inoperative, and the air drag on the back disk causes it to lag the maximum amount. Under this condition the filters on one disk are adjacent to the clear area on the other disk, thereby providing in front of the picture tube a succession of six color filters, as required for color operation.



When the receiver is switched to monochrome, the brake is engaged and the motor is reversed. The disk assembly is rapidly brought to a stop and is then slowly rotated in a backward direction by the motor. The centrifugal catch stops the back disk, while the front disk continues to rotate until the back disk leads the front disk by the maximum amount, at which time the centrifugal catch actuates the microswitch, turning off the motor. This leaves the two clear areas of the disks adjacent to each other and over the tube face, as is required for monochrome.

The brake mechanism consists of a simple friction plate notched on its periphery and mounted under tension between two felt plates keyed to the disk drive shaft. During operation, a stationary latch engages the brake plate at its periphery.

The reluctance-type generator consists of a magnetically hard U-shaped stator with a coil around each leg and a magnetically soft rotor. It is magnetized by discharging a heavy electrolytic condenser through the coils while the generator is running.

The stator and rotor pole pieces are shaped to provide a saw-tooth wave output of approximately 200 v peak-to-peak. This saw tooth has a very steep downward slope of approximately 10 v per degree disk rotation, which limits the variation of disk phase to approximately $\pm 2°$ over the wide range of operating conditions described previously.

Precision ball bearings with sealed-in lifetime lubrication are used to float the color disk drive shaft. These require no care, retain low and constant friction over a wide range of operating conditions, and eliminate any oil seepage onto the color disks.

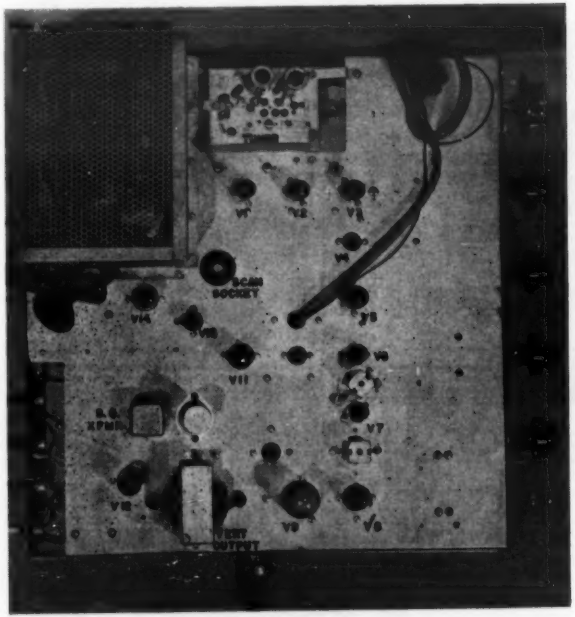


Fig. 11. Combination receiver chassis, top.

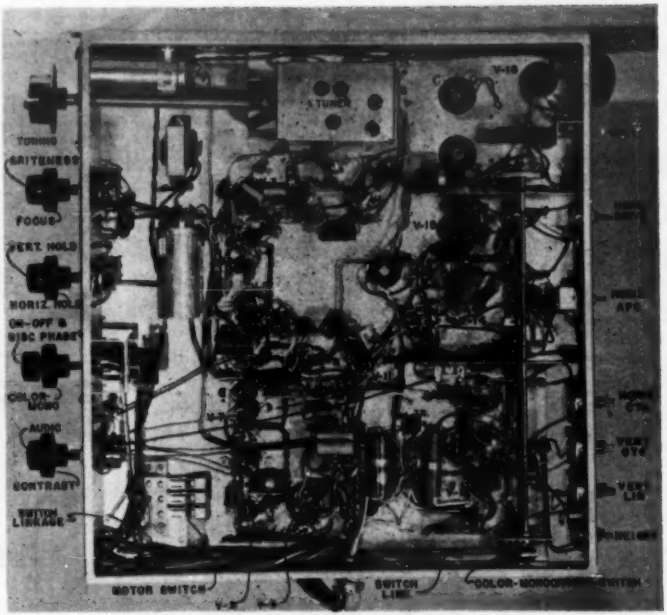


Fig. 12. Combination receiver chassis, bottom.

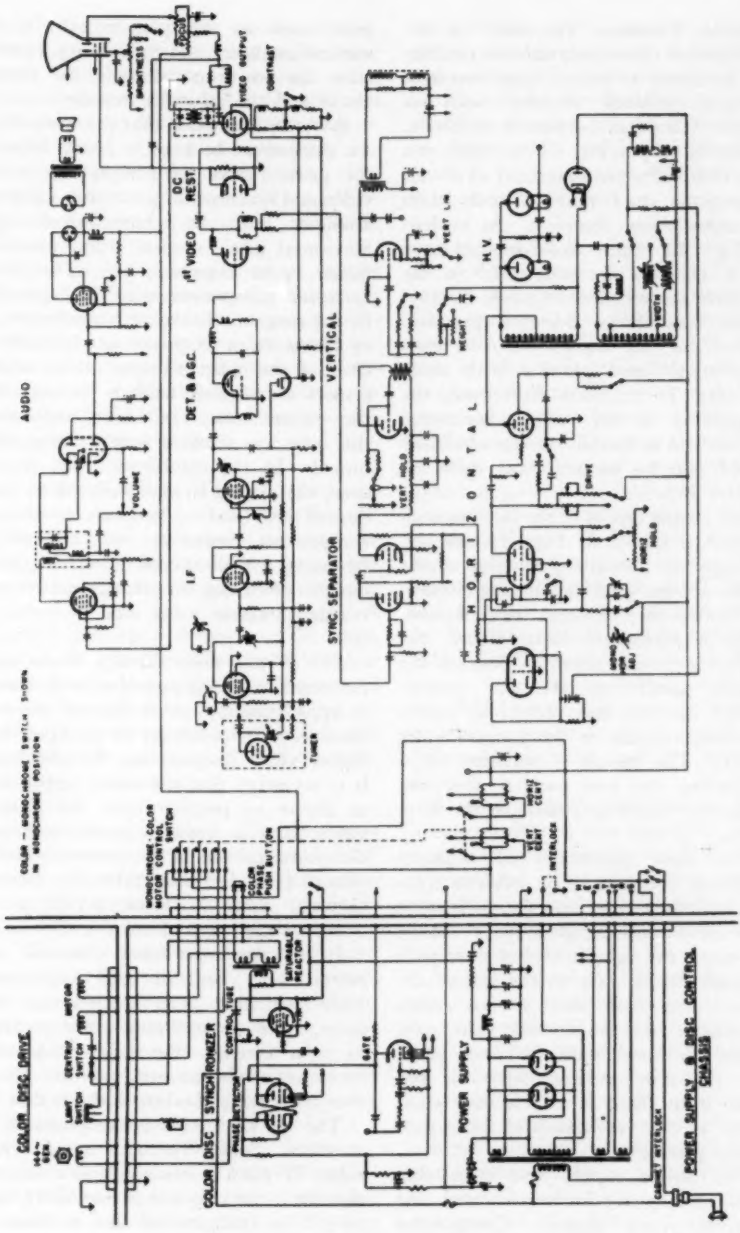


Fig. 13. Combination receiver schematic.

Chassis Component Placement. In the combination color-monochrome receiver it is necessary to switch components of normally isolated circuits, such as vertical deflection, horizontal oscillator, horizontal output, etc. This results in a somewhat different placement of chassis components than that normally used on monochrome receivers. As evident in Fig. 12, most color-monochrome switch contacts are connected to the so-called screw-driver controls located on the rear chassis skirt. A practical location of the switch is, therefore, adjacent to, and parallel with these controls. To maintain short leads, the components of the various horizontal and vertical deflection circuits obviously should also be located near their respective switches.

The chassis layout of the combination receiver is shown in Figs. 11 and 12. Arranged in line along the rear of the chassis are the vertical scanning circuits, the horizontal oscillator circuits and, under a perforated metal shield, the horizontal output circuits. Beneath the chassis, parallel to the rear "screw-driver" controls and under the corresponding circuits, is the ganged wafer switch. The switch is actuated by a connecting rod and rocking arm mechanically linked to a knob on the front panel.

The close placement of adjacent electrical components is evident from a cross-comparison of the schematic with the chassis arrangement. From the RF tuner, the signal travels a short path through the IF strip to the second detector and first and second video amplifiers. At the second video amplifier the signal branches to the audio and the synchronizing separator circuits; from there it travels over short paths to the vertical and horizontal scanning sections.

The power supply and color disk synchronizing circuits are mounted on a separate small chassis. Components sensitive to a 60-cycle/sec magnetic field, such as the picture tube and vertical oscillator, are thereby separated from the power transformer, the filter choke and the saturable reactor.

It is very important that the 60-cycle/sec component be kept to 50 db below the peak-to-peak color signal in both video and synchronizing circuits. Larger amounts may be characterized by horizontal jitter, vertical jitter, picture flutter, poor interlace, etc. The 60-cycle/sec component may be injected by the magnetic fields mentioned above, by filaments, or by power supply ripple. One of the most sensitive areas with respect to magnetic fields is the neck of the picture tube. In earlier receivers this tube was shielded with a mu-metal funnel. In the combination set, however, the overall hum is reduced to the desired low level by properly orienting components radiating 60 cycle/sec, by using a well-filtered power supply, and by observing the usual practices of twisting filament leads, etc.

RF, IF and Video Circuits. Since the horizontal scanning rate of color pictures is approximately twice that of monochrome, it is important to preserve the higher video frequencies. In addition, it is necessary that the video output be as linear as possible over the entire video band in order to avoid contrast distortion in the color picture. Such distortion is less noticeable in monochrome, since in color television it manifests itself as poor color rendition.

It has also been found desirable to switch both contrast and brightness when switching from monochrome to color, since an optimum color picture as seen through the color disk has excessive brightness and contrast when seen in black-and-white without disk.

The RF-IF section is composed of a standard Sarkes-Tarzian tuner, two tuned IF pairs in cascade, and a second detector. Its response is essentially flat to 3.7 mc (megacycles) and is down 3 db at 4 mc.

The video amplifier consists of one-half a 12AU7 triode first video stage and a 6AQ5 output video stage. The second half of the 12AU7 is used as a d-c restorer. With three volts peak-to-peak input, 120 v peak-to-peak are realized at the kinescope grid. The 6AQ5 stage is capable of 130 v peak-to-peak without appreciable amplitude distortion.

A degenerative-type contrast control in the 6AQ5 cathode circuit is frequency compensated to provide essentially uniform frequency response throughout the control range. For monochrome the maximum video level is lowered by switching a 560-ohm resistor into the contrast control circuit.

Audio Circuits. These circuits are identical to those used in monochrome. The IF trap attenuates the sound carrier approximately 10 db. The 4.5-mc intercarrier signal is removed from the plate circuit of the video output stage. A 6AU6 amplifier drives a 6T8 stage, which is a combination ratio detector and first audio amplifier. Additional audio amplification is provided by the 6V6GT audio output stage, which also acts as a dropping resistor and regulator for the 150-v supply.

Synchronizing Circuits. Synchronizing signals are derived from the 12VH7 first video amplifier. This provides signals of essentially constant amplitude independent of contrast adjustment.

The noise immunity of the synchronizing signal separator is improved through the use of a combination long- and short-time-constant coupling circuit. The usual phase-inverter type second triode delivers the separated signals to the vertical oscillator and the horizontal phase detector diode.

Vertical Oscillator and Output Amplifier. A 12BH7 is used as a vertical blocking oscillator and output stage. Necessary circuit changes between color and monochrome are provided by five SPDT switches which act at the following points: (1) vertical oscillator grid return resistor (vertical hold), (2) *RC* charging network in the plate circuit of the vertical oscillator, (3) height controls, (4) linearity controls, and (5) centering controls.

Horizontal Oscillator and Output Amplifier. A 6AL5 phase detector controls the 12BH7 horizontal multivibrator in the usual manner. A 6BG6G horizontal output tube, a 6U4GT damper and a pair of 1X2 voltage doubling rectifiers provide adequate 55° scan and a h-v potential of approximately 15 kv.

Nine monochrome-color SPDT switches provide circuit changes at the following points: (1) AFC time-constant capacitor in the grid circuit of the horizontal oscillator, (2) flywheel *LC* tuning capacitor in the plate circuit of the horizontal oscillator, (3) fixed resistor in series with the horizontal hold control, (4) horizontal drive control potentiometers, (5) *RC* charging network in the output of the horizontal oscillator, (6) 6BG6G screen voltage, (7) yoke tap on the horizontal output transformer, (8) width controls, and (9) centering controls.

A special horizontal output transformer developed specifically for use on both color and monochrome frequencies is employed. The construction of this transformer is conventional and a ferrite core is used. Pertinent constructional details are shown in Fig. 14.

In this type of dual-frequency transformer the leakage reactance may resonate with the distributed capacitance, resulting in undesirable "ripples" on the left edge of the raster. This effect is eliminated in the combination receiver by connecting, for monochrome, a highly damped tuned circuit in the transformer secondary. As indicated in Fig. 13, this circuit is a parallel combination of a 200-μh (microhenry) inductance, a 1000-$\mu\mu$f (micromicro-

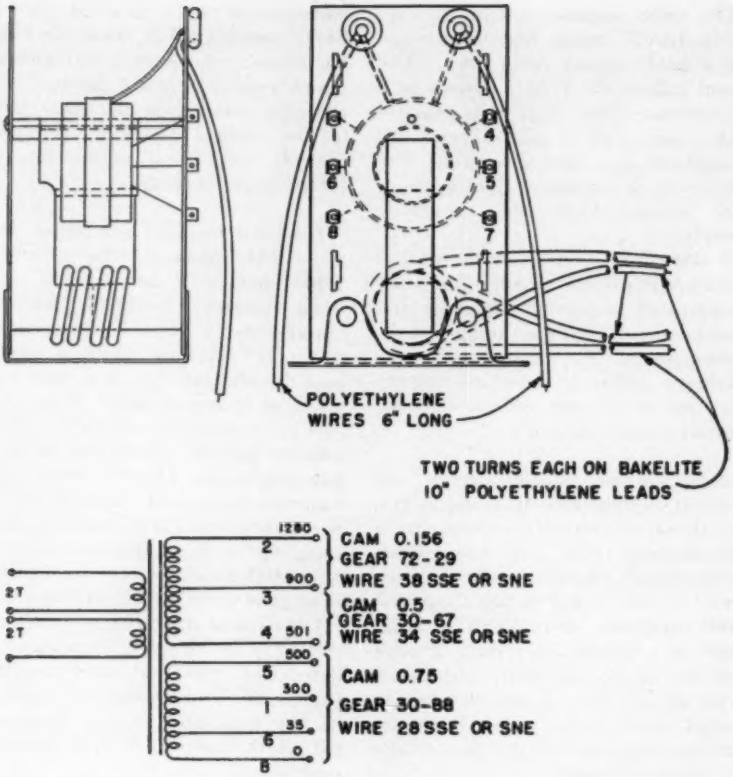


Fig. 14. Dual frequency horizontal output transformer.

farad) capacitance, and a 5000-ohm resistor.

A conventional monochrome anastigmatic scanning yoke is used. This again employs a ferrite core. The vertical and horizontal windings are of a type with inductances of 50 mh (millihenry) and 8.3 mh, respectively.

Color Disk Synchronizing Circuits. As indicated in Fig. 13, a pulse gate, a phase detector, and a saturable reactor control tube are used for color disk synchronization. The saw-tooth wave produced in the disk shaft generator is applied to both sections of the phase detector tube. This tube conducts momentarily only when excited by the vertical pulses. The clamped voltage appearing at the grid of the control tube is therefore dependent upon the relative phase relationship between the vertical pulses and the locally generated saw-tooth wave. A variation of control tube current causes a corresponding change in the degree of saturation of the motor control reactor, thereby varying the speed of the color disk.

If, for example, the disk momentarily slows to slightly below synchronous speed, the point on the locally generated saw-tooth wave at which the vertical

pulses clamp moves upward, thereby decreasing the bias on the control tube. The increased control tube current increases the degree of saturation in the motor control reactor, thereby increasing motor and disk speed to synchronism.

The pulse gate provides velocity correction of the color disk. This tube is normally conducting, thereby preventing the vertical pulses from reaching the phase detector. The locally generated saw-tooth wave from the generator is differentiated and applied to the grid of the gate tube in such a manner as to make it nonconducting only during the downward steep portion of the saw-tooth wave. Thus the operation of the phase detector is permitted during this period only. With this arrangement the *average* bias appearing at the control-tube grid is high when the disk is running considerably over speed, and low when running considerably under speed. This provides effective disk velocity correction.

In the color disk synchronizing circuits, as in most servomechanisms, an anti-hunt network is required to eliminate hunting. Such a network is provided by the 20,000-ohm resistor, 16-μf electrolytic capacitor, and 2-μf paper capacitor at the screen of the control tube and the 250,000-ohm potentiometer between the saw-tooth generator and ground. This network returns from the control tube to the phase detector the necessary amount of phase-shifted anticipating voltage to prevent hunting. Optimum anti-hunt adjustment is provided by the 250,000-ohm potentiometer.

Changes in type of color disk (as to its inertia), motor, or saturable reactor usually require corresponding changes in the anti-hunt feedback network.

Color Disk Synchronizing Operation. In effect, three separate operations pull the disk into synchronism and keep it there. When power is first applied, the centrifugal switch in the motor is closed, shorting the a-c windings of the saturable reactor. Full line voltage is thereby applied to the motor, causing rapid acceleration of the color disk to near synchronous speed. The centrifugal switch then opens and the saturable reactor with its associated circuits takes control. The velocity correcting circuits bring the disk to synchronous velocity, at which time the phasing circuits bring the disk into exact phase and maintain it there. Only ten to fifteen seconds is required to bring the 22½-in. disk into synchronism and phase from a standstill. When running, the disk synchronizes in less than one second.

Power Supply. The power supply in the combination color-monochrome receiver is similar to that of any good monochrome receiver. As discussed previously, both the 60- and 120-cycle/sec hum components are kept very small. Decoupling is provided between the terminals supplying the disk synchronizing circuits and those supplying the remainder of the receiver. This eliminates any low-frequency variation of picture size, brightness, etc., induced by the action of the color disk synchronizing circuits. These circuits require a relatively constant current of 10 to 30 ma (milliampere) while the disk is in synchronism, but during the time the disk is being pulled into synchronism the current may vary at a slow rate between approximately 0 and 60 ma, with a corresponding induced variation in power supply voltages.

Two 5V4G cathode-type rectifiers prevent high-voltage surges when the receiver is first energized. After filtering, 390 v at 240 ma is available.

A selenium half-wave rectifier is connected to one side of the high-voltage winding of the power transformer to provide the negative voltages for the electrostatic picture tube focus and the disk control circuits.

Slave Color Receiver

Of universal interest to present television set owners is how to use present

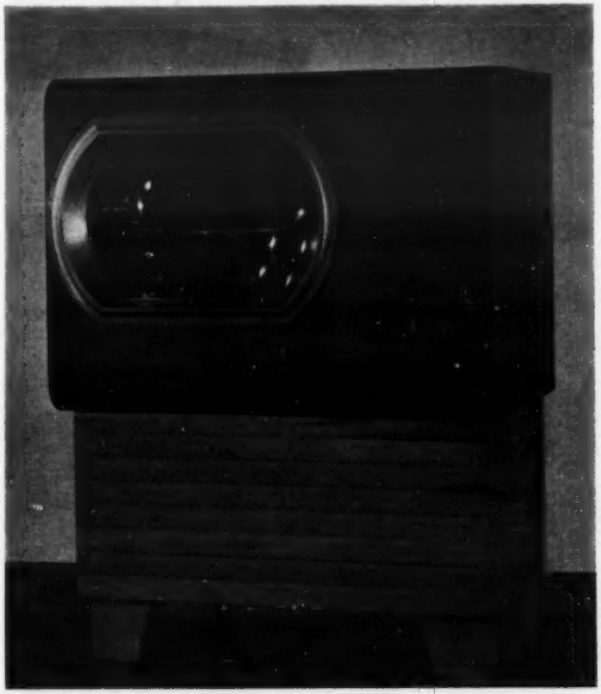


Fig. 15. Slave color receiver, front.

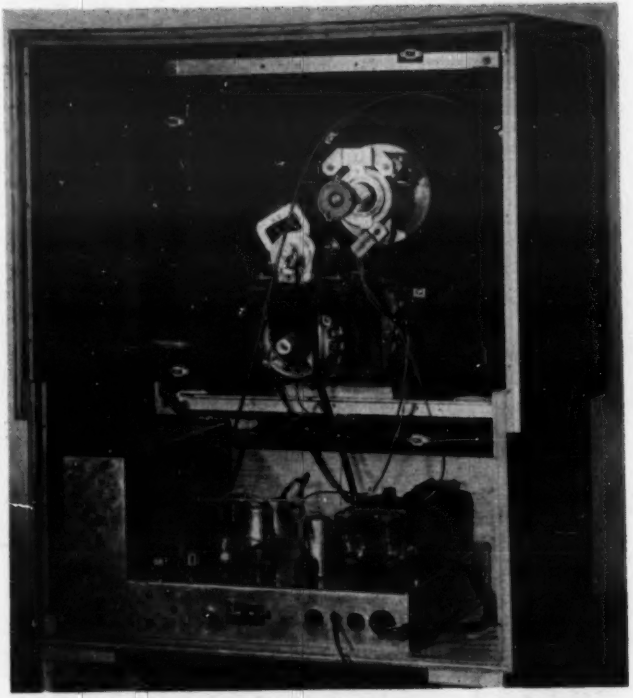


Fig. 16. Slave color receiver, back.

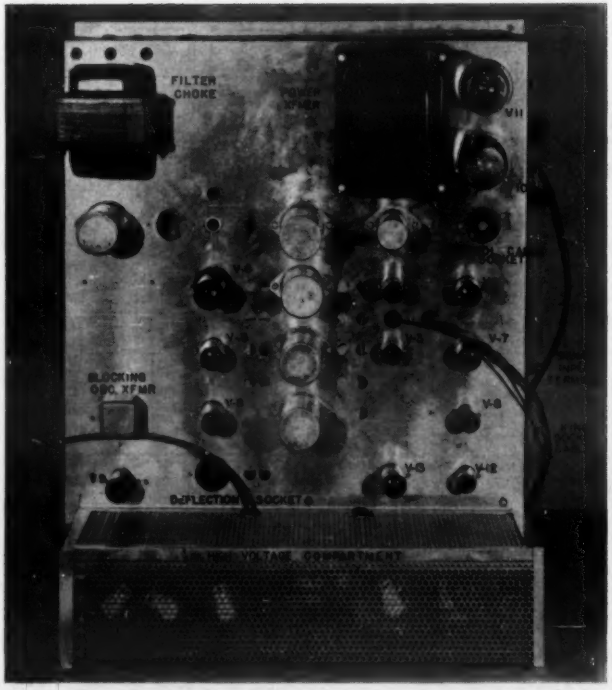


Fig. 17. Slave color receiver chassis, top.

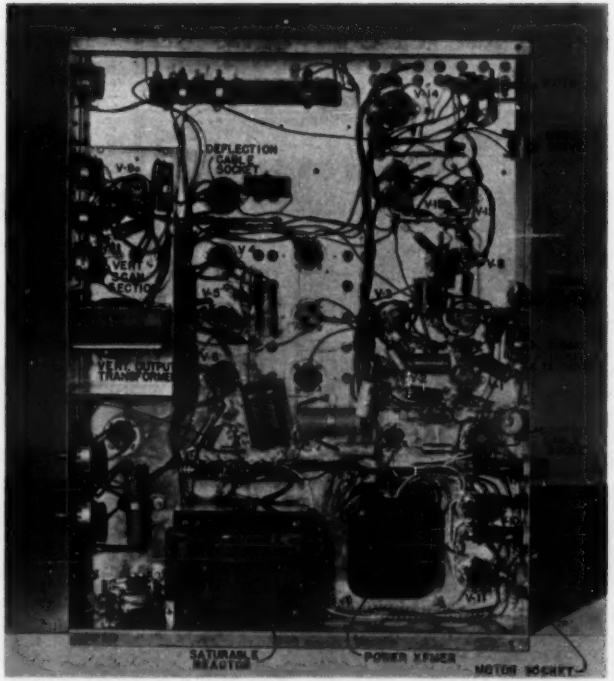


Fig. 18. Slave color receiver chassis, bottom.

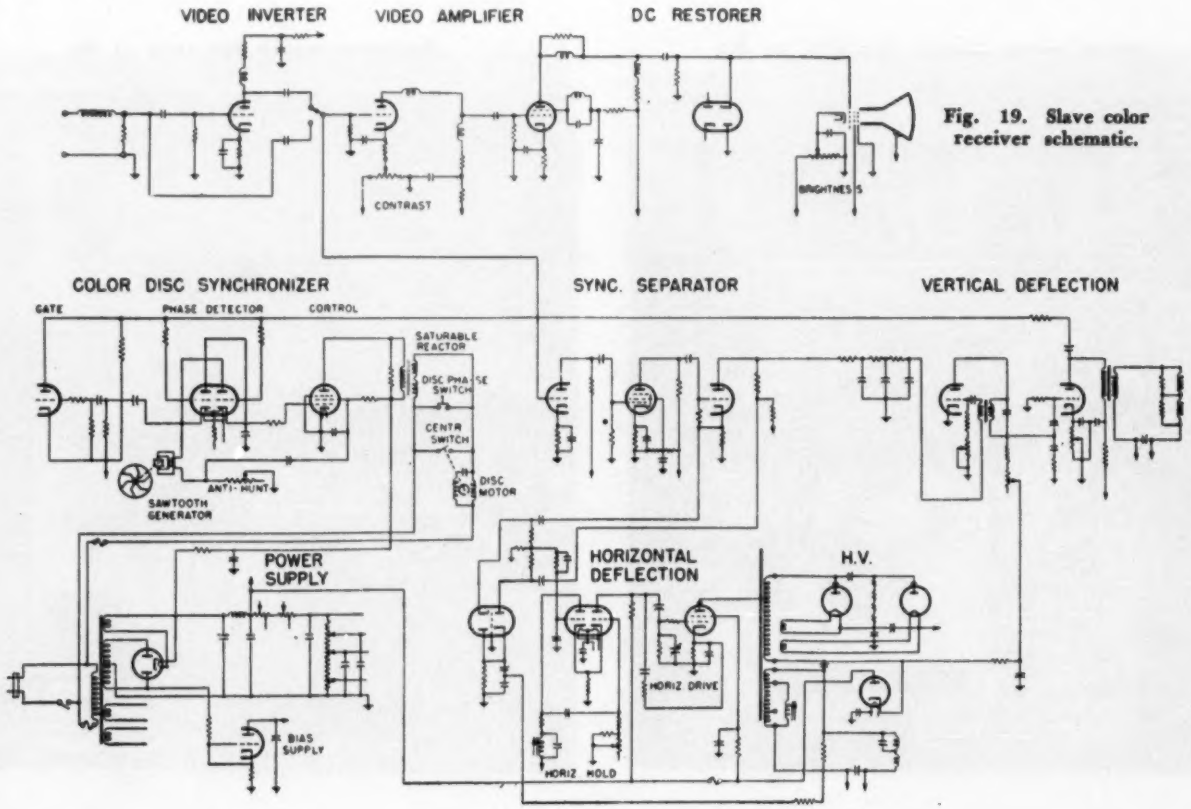


Fig. 19. Slave color receiver schematic.

monochrome sets to receive color. While adaptors may be used to permit reception of color broadcasts in black-and-white, and converters may be used to change these to color, a preferred method is that of using a slave color receiver. This unit scans at color frequencies only and presents a color picture by means of its own separate tube and color disk. It requires from the monochrome receiver only composite video. Sound is derived from the monochrome receiver in the usual manner. Since the slave receiver requires no RF, IF or audio stages, it is considerably less expensive than a complete color receiver.

The slave color receiver is shown in Figs. 15 and 16; the chassis is shown in Figs. 17 and 18; and its schematic is given in Fig. 19. Requirements for the various sections of this receiver are essentially the same as those described for the combination receiver. A few departures, however, are described in the following paragraphs.

Physical Characteristics. The overall dimensions of the slave color receiver are somewhat less than those of the combination receiver, being 27½ in. wide by 33 in. high by 20 in. deep. Sixteen tubes are employed, including rectifiers.

Only a single chassis is used, the power supply and color disk drive components being arranged in such a manner as to produce no undesirable effects from their magnetic fields.

The lower of the two front panel knobs controls the off-on switch and the contrast. The upper knob is rotated to control the brightness and depressed to bring the color disk to the proper phase.

Video Circuits. Two stages of conventional design are employed. Video response is flat within 2 db from 30 cycle/sec to 4 mc with a voltage gain of approximately 115. A 4.5-mc sound trap in the 6AQ5 screen circuit provides 35-db rejection. A polarity reversal stage with unity gain provides operation with either polarity of incoming composite video. Since the contrast control is mounted at a distance from the chassis, a somewhat unconventional circuit is used in which a variable positive bias is applied to the cathode of the first video stage. With the constants used, this circuit gives adequate contrast range with negligible frequency discrimination.

Vertical Oscillator and Amplifier Circuits. To insure reliable interlace these circuits are placed in a shielded compartment. This eliminates interference from both nearby electrical fields and from the magnetic fields of the power transformer and saturable reactor.

III. CBS Color-Television Broadcast Facilities

Conversion of the RCA Monochrome Field Camera for Color Television

The first prototype conversion of the RCA Field Television Camera Chain was undertaken by the RCA Terminal Facilities Engineering Group in Camden, N. J., between May and July of 1950. Circuit changes and additions, which CBS had used satisfactorily in earlier color television equipment, were incorporated into several sections of the converted equipment. During 1950 a second and third camera chain were converted in the CBS General Engineering Department, incorporating improvements resulting from experience gained through use of the first equipment. These, and a few additional improvements, are now being incorporated in a new series of color camera chains, again using standard monochrome equipment as a basis.

In the first three conversions type TK-30A field camera chains with studio

Fig. 20. RCA monochrome camera converted for color, front view; lens turret removed and added color disk in place.

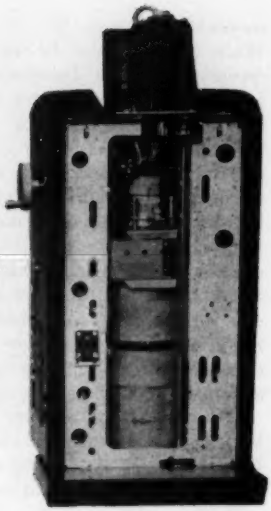


Fig. 21. RCA monochrome camera converted for color; top view, showing color drive assembly with added color-disk drive motor.

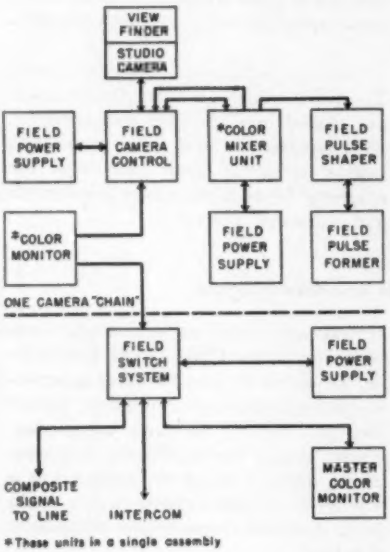


Fig. 22. RCA single camera chain converted for color, block diagram.

type RCA M126000 cameras were used. Figures 20 and 21 show how the color disk housing on these cameras is incorporated in a new front cover. Since the studio and field type cameras are identical as to circuit and chassis construction, the field camera with similar mechanical changes to the cover can also be successfully modified.

A block diagram showing the signal connections of a single camera chain, complete with synchronizing signal generator, is shown in Fig. 22. It will be noted that the connections are identical to those used for monochrome except for the addition of cables to the color mixer amplifier. The modifications necessary to each of the units shown in Fig. 22 will be described in some detail in the following sections.

Synchronizing Signal Generator Pulse Former. The principle changes to this unit are:

(a) Shift the master oscillator horizontal scanning frequency to 58,320 cycle/sec.

(b) Change the cathode bias resistors of the counters so that the first three counters count down 9-9-5 to give the 144-cycle/sec vertical triggering pulse, and the fourth counter counts down, 3 to 1, to give the color triggering pulse.

(c) Install three double triode miniature tubes on a small shelf mounted between terminal boards. These generate a color drive pulse and a color synchronizing pulse; both at a 48-cycle/sec rate. The color drive pulse is used for two purposes: first, to provide a trigger pulse for the color mixer red-gating circuit so that the red video channel is always properly identified (to be further described later); second, to provide a variable time delay to center exactly the timing of the color synchronizing pulse between the first and second equalizing pulses.

The color synchronizing pulse is introduced over an unused terminal and cable connection into the pulse shaper unit, where it is mixed with composite synchronizing signal.

The above describes an earlier method of generating a color synchronizing pulse, and while convenient it is not satisfactory when using step counters, since there is excessive time delay between the front edge of the original 58,320-cycle/sec trigger pulse and that of the 48-cycle/sec pulse from the fourth counter.

A more recent method is indicated in Fig. 23. A sufficiently wide color drive pulse, *b*, is generated to gate in only the first equalizing pulse of every third field. This single equalizing pulse, which does not shift in time phase, is used to trigger the color delay multivibrator. The resulting pulse is in turn differentiated and its trailing edge is used to trigger the color synchronizing pulse multivibrator. The width of the delay pulse thus controls the start of the color pulse generator, and the width of the color synchronizing pulse can then be adjusted to the required value of 0.04 *H*. The color synchronizing pulse should be properly centered between the first and second equalizing pulses by use of a trigger-time-base oscilloscope.

It is preferable to supply power for the filaments and the master oscillator lock-in from a small 144-cycle/sec generator driven by a synchronous motor. This avoids 60-cycle/sec phase modulation in the generated pulses due to poor filament grounds or common cathode-filament ground returns. Three miniature tubes on a small sub-chassis are used to generate a 60-cycle/sec comparison pulse for afc locking. This unit counts down 12 to 1 from the 720-pulse/sec output of the second counter. In some conversions a 4-to-1 and a 3-to-1 counter were used to obtain the 12-to-1 ratio with better stability. No problems were encountered in operating synchronizing signal generators expressly designed for color standards on a 60-cycle/sec power source.

Synchronizing Signal Pulse Shaper. In order to produce the pulse width required for the higher scanning speeds, *RC* changes are necessary in all the multivibrator pulse generating circuits. Pulse slopes with fast enough time-of-rise to meet FCC standards as shown in Fig. 1 can be obtained without difficulty. To inject the color synchronizing pulse directly into the synchronizing pulse mixing and clipping circuits, a small miniature tube is mounted on the chassis with its plate circuit connected in parallel with the composite synchronizing pulse mixing tubes.

Camera. Two major changes are required in the camera: (a) a new horizontal scanning circuit to supply the higher scanning power necessary for camera tube deflection; and (b) the addition of the color disk to the front end of the camera with accompanying

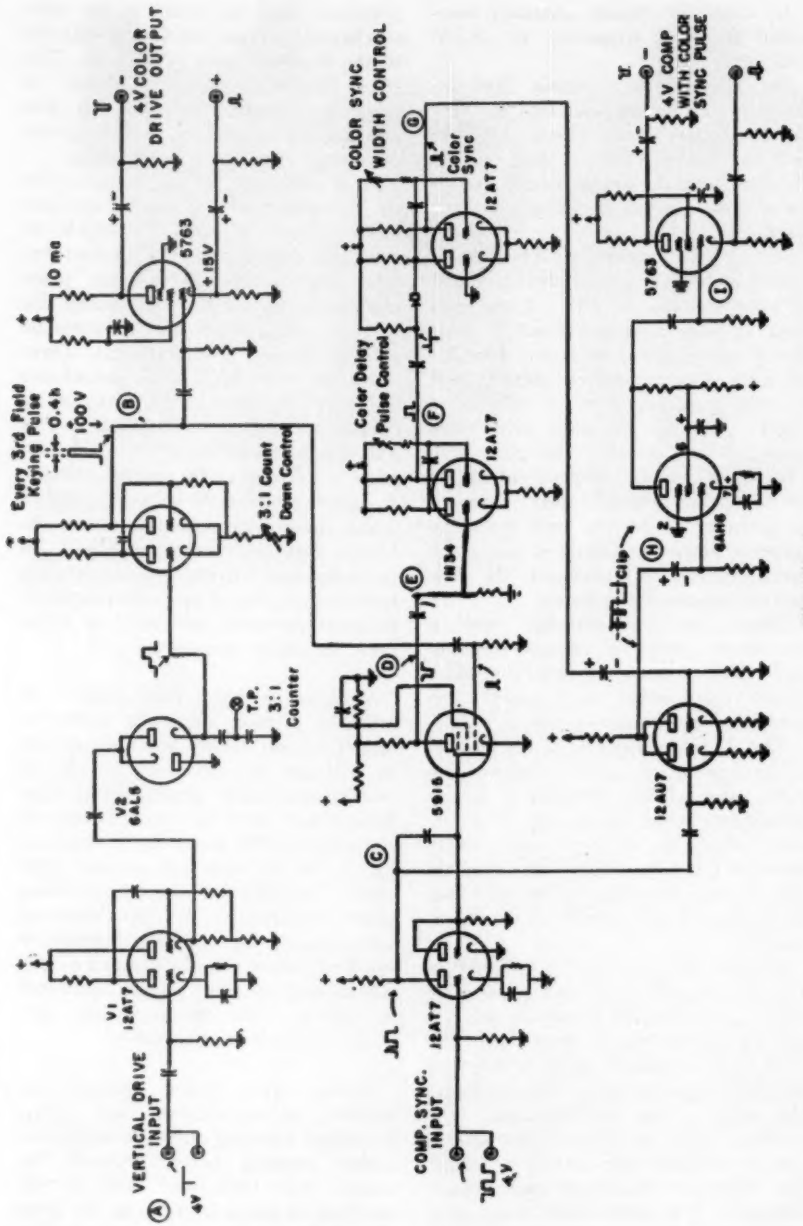

4V COLOR DRIVE OUTPUT
10 ms
5763
+15V
Every 3rd Field Keying Pulse
0.4h
100V
3:1 Count Down Control
T.P. 3:1 Counter
V2 6AL5
V1 12AT7
VERTICAL DRIVE INPUT
4V
COLOR SYNC WIDTH CONTROL
Color Sync
12AT7
Color Delay Pulse Control
1N34
5915
COMP. SYNC. INPUT
4V COMP WITH COLOR SYNC PULSE
6AH6
12AU7

Fig. 23(a)

mechanical modifications of the focusing mechanism.

The horizontal scanning circuit used in the second and third conversions has proved entirely reliable in extensive use in industrial color camera equipment. This circuit is shown in Fig. 24. The normal output transformer is replaced with a specially designed transformer using grooved textolite and formex forms placed over dual three-mil laminated hypersil cores.

Instead of the +360-v unregulated source normally used, the damping tube is used to provide a rectified boost voltage. This avoids any 120-cycle/sec ripple component that might cause a 24-cycle/sec phase jitter in the horizontal scanning. As in black-and-white service, a scanning current of 1 amp peak-to-peak is normally required. This circuit, however, is capable of supplying a linear scanning current of 1.3 amp peak-to-peak, which allows sufficient overscanning to prevent burn-in of the mask on the target.

Installation of the color disk drive assembly requires that the lens turret and light trap be moved forward and that the front face plate of the camera be replaced. To permit all lenses to be focused to infinity, the back edge of the camera tube bakelite mask retainer ring is undercut by approximately $\frac{1}{8}$ in. This allows the tube to be pushed sufficiently forward into the focus coil assembly.

The color disk, which rotates at 720 rpm, is mounted directly on the end of a $\frac{1}{4}$-in. shaft which extends lengthwise through the top portion of the camera and runs in oilite sleeve bearings mounted on the new front face plate and the rear of the camera chassis. At one end of the shaft is mounted a twelve-tooth sprocket which is coupled to a six-tooth sprocket on the motor by means of a Gilmer timing belt (mold No. 9164). The motor is a one-hundredth horsepower salient pole synchronous type (Cyclohm model No. SWC2914-XL). It operates from a 48-cycle/sec, 115-v, 25-w amplifier located in the color mixer chassis. This arrangement permits continuous electrical phase adjustment. Proper phase adjustment occurs when the spokes of the disk, separating adjacent color filters, coincide with the locus of the scanning beam in the camera tube. This condition is necessary in order to avoid color carry-over from one field to the next. Since the optical image is inverted on the photocathode and the raster is therefore scanned from bottom to top, it follows that the disk, as viewed in Fig. 20, must turn clockwise. To meet the colorimetric requirements discussed previously in this paper, No. 25 red, No. 47, half-density blue, and No. 58,

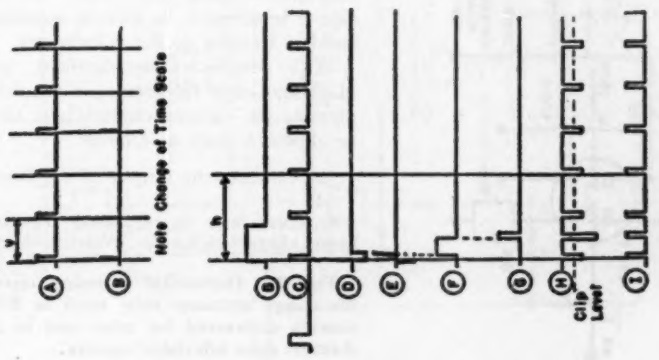
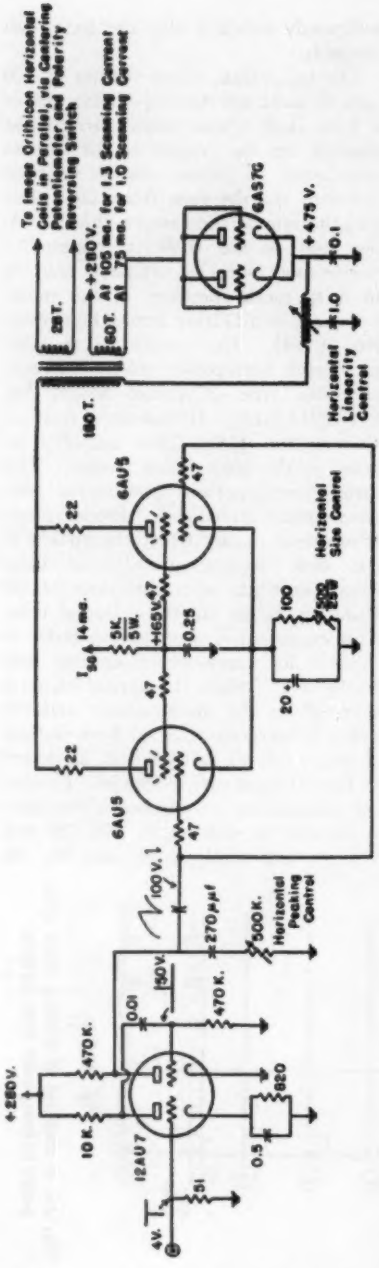


Fig. 23(b)

Fig. 23. A method of adding color sync pulse to composite sync signals.



three-quarters density green color filters are used.*

Camera Viewfinder. The circuit modifications in the viewfinder are of a minor nature, mostly involving *RC* changes. The original deflection yoke and transformer may be retained if the horizontal coils of the yoke are reconnected in parallel in order to obtain a sufficiently fast retrace. This is required since the narrow image-orthicon target blanking derived from the vertical and horizontal driving pulses is used for blanking of the picture tube in the viewfinder.

Camera Control Unit. In this unit it is necessary to:

(a) Substitute a 7RP4 picture tube for the 7CP4. This provides a brighter picture as is desirable for monitoring in color;

(b) Add a high-voltage supply of at least 10,000 v (for the 7RP4 picture tube);

(c) Modify the horizontal scanning circuit;

(d) Provide mechanical modifications necessary to mount the new tube in place; and

(e) Move the front panel controls to provide space for a color disk and its enclosure in front of the picture tube.

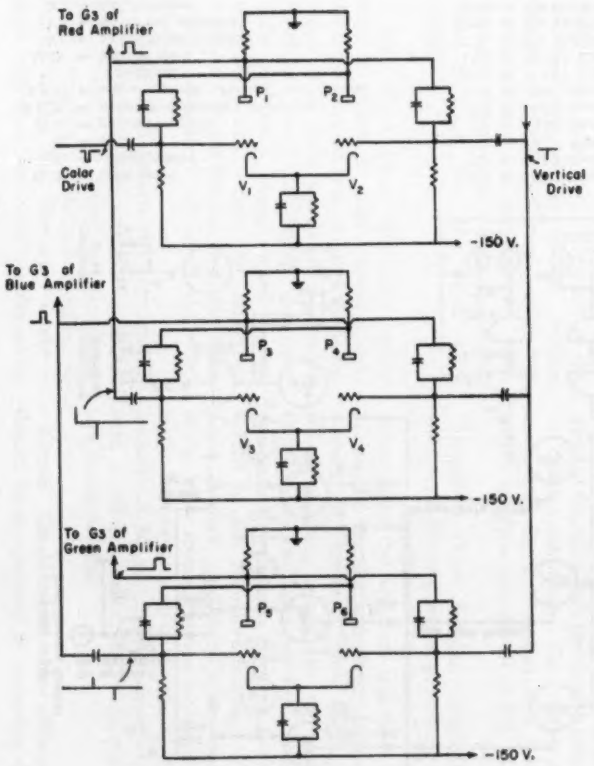
Not all of these changes are necessary if the original 7CP4 picture tube is used as a monitor in black-and-white (color standards without color disk). In this case it is advisable to include a picture monitor in color in the color mixer.

With this latter arrangement, i.e., black-and-white monitoring of the color picture, the camera control unit need be modified only as follows:

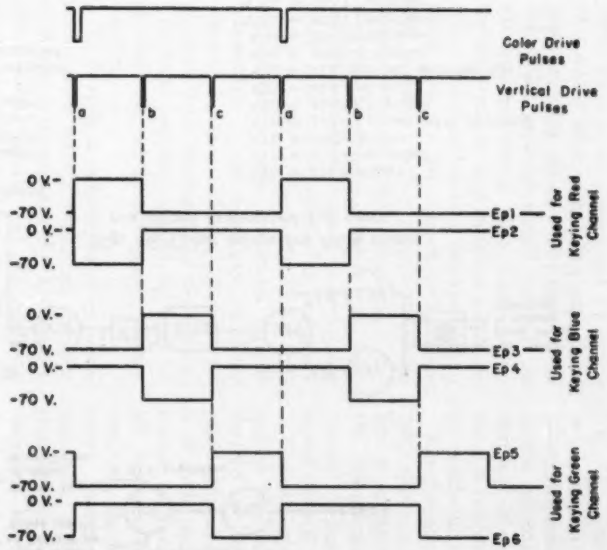
(a) Connect the output of the fourth

* Numbers refer to published transmittance characteristics for Wratten filters.

Fig. 24. Horizontal scanning circuit for image orthicon tube used in RCA camera converted for color and in industrial color television camera.



(a)



(b)

Fig. 25. Color gating pulse generator. (a) Schematic; (b) Waveforms.

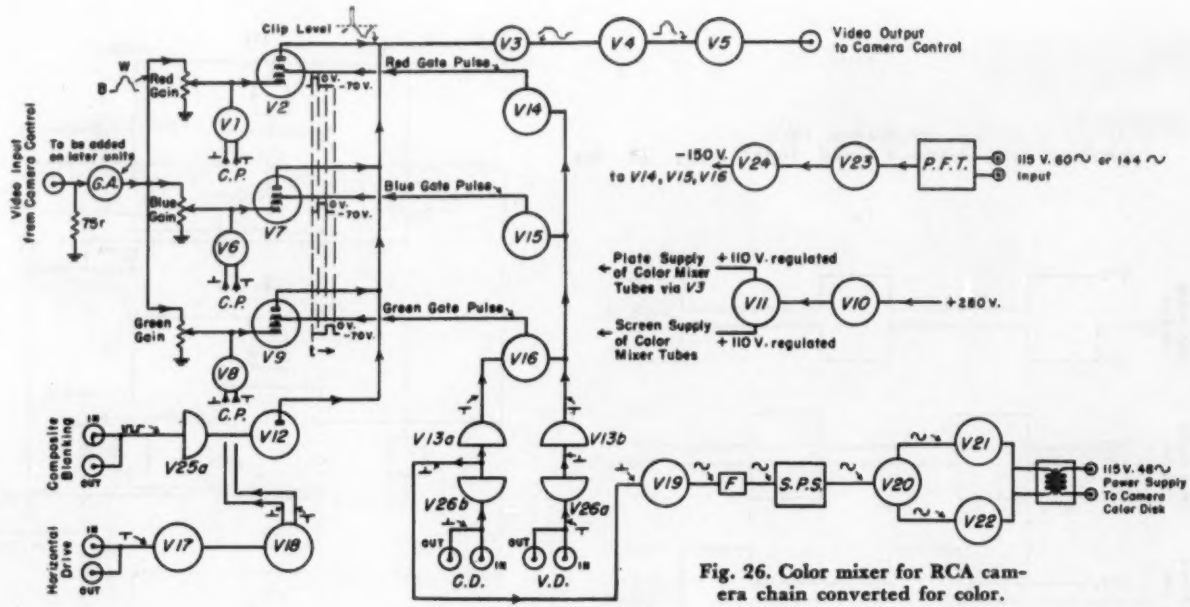


Fig. 26. Color mixer for RCA camera chain converted for color.

Legend:

C.D. = color drive
C.P. = clamp pulses
F. = filter
G.A. = gamma amplifier
P.F.T. = power and filament transformer
S.P.S. = selsyn phase shifter (continuous rotation)
V.D. = vertical drive
V1 = 6AL5 diode clamper
V2 = 6AU6 red amplifier
V3 = 6AL5 clipper
V4 = 6AC7 amplifier
V5 = 6AG7 output
V6 = 6AL5 diode clamper
V7 = 6AU6 blue amplifier
V8 = 6AL5 diode clamper
V9 = 6AU6 green amplifier
V10 = OB2 regulator
V11 = 12AT7 voltage regulator
V12 = 12AT7 clipper amplifier
V13a = 6J6 amplifier
V13b = 6J6 amplifier
V14 = 6J6 flip-flop
V15 = 6J6 flip-flop
V16 = 6J6 flip-flop
V17 = 12AT7 amplifier
V18 = 6AQ5 output
V19 = 12AU7 square wave generator
V20 = 12AT7 amplifier
V21 = 6L6 push-pull
V22 = 6L6 push-pull amplifier AB_2
V23 = 6X5GT rectifier
V24 = VR150 regulator
V25a = 12AT7 amplifier
V26a = 12AT7 amplifier
V26b = 12AT7 cathode follower

video stage to an output jack by means of a 6AG7 tube with a low-impedance plate coupling circuit. The signal from this point may be passed through an external connection to a color mixer, for color mixing and injection of blanking. The signal is then returned to an input jack on the control unit, where the signal is further amplified in the normal manner. Since blanking is not used in this camera control unit, tube V8 can be removed and the additional 6AG7 tube can be installed in its place.

(b) Parallel the horizontal yoke coils and install a new horizontal output transformer of the type used in color receivers. These circuits should be powered from the regulated d-c supply. The boost winding should be used to provide the additional plate voltage required.

(c) Provide a definite color sequence presentation on the waveform monitor so that both the amount of red, blue and green video signals and the blanking constants can be observed and individually adjusted. The 48-cycle/sec color drive pulse can be applied to the synchronizing circuit of the vertical sweep, preferably through tube V6, connected as a cathode follower. This provides the necessary isolation to prevent kickback into the color drive circuits.

Color Mixer Unit. One color mixer unit is added to each camera chain. Its main purpose is to channel the video signal into three separately adjustable amplifiers, each amplifying only one color and each being turned on sequentially, i.e., when the image is televised through the red filter, the video signal is amplified only in the red video channel.

Figure 25 illustrates the color-gating pulse generator which controls the operation of the color mixer. A functional block diagram of the color mixer is shown in Fig. 26. The color mixer—front view and rear view—is shown in Fig. 27. This unit with cover removed is shown in Fig. 28. In this unit composite receiver blanking is injected in the normal manner, clipped, amplified and if so desired, returned to the camera control unit for further addition to synchronizing signals.

For the accurate rendition of delicate color shades a gamma correction amplifier is incorporated to compensate for the compressed black output of the typical kinescope (light output vs. signal output).

The 48-cycle/sec, 115-v power required by the camera disk motor is derived as follows: The color drive pulse actuates a multivibrator to generate a 48-cycle square wave, which is converted to a sine wave by filtering out all harmonics above 48 cycles. The resultant signal is coupled through a selsyn motor to a push-pull output amplifier. A standard 5000-ohm output transformer is used to couple the amplifier to the camera disk motor. As mentioned previously, the selsyn permits convenient and accurate adjustment of the color disk phase with respect to camera scanning. The circuit arrangement for the camera disk motor power supply is also shown in Fig. 26.

Regulated Power Supplies. Originally, additional filtering was required on the +360-v unregulated terminal since power from this terminal was used for horizontal camera scanning. In later conversions, however, only the horizontal scanning circuit of the viewfinder is operated from this terminal and the horizontal camera scanning is connected to the regulated source. If a slight amount of 120-cycle/sec ripple in the 360-v terminal causes interference in the horizontal scan of the viewfinder, a small 4-h, 80-ma, choke in conjunction with a 10-microfarad, 600-v capacitor will prove helpful.

General Considerations. No difficulty should be experienced in operating the

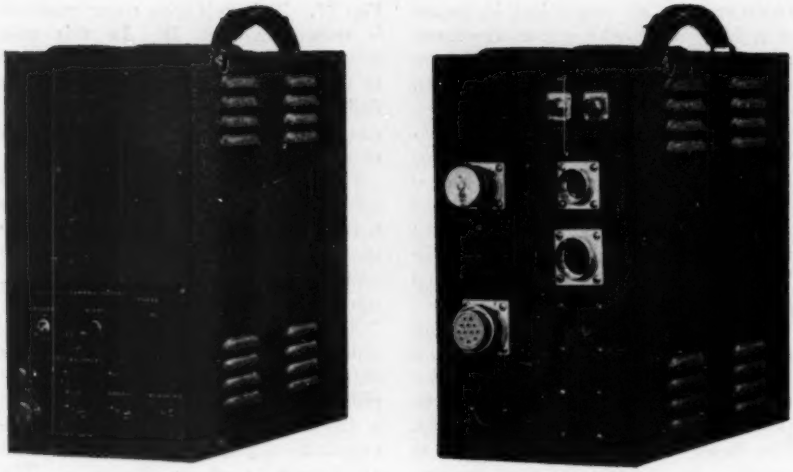


Fig. 27. Color mixer for RCA camera chain converted for color, front view and rear view.

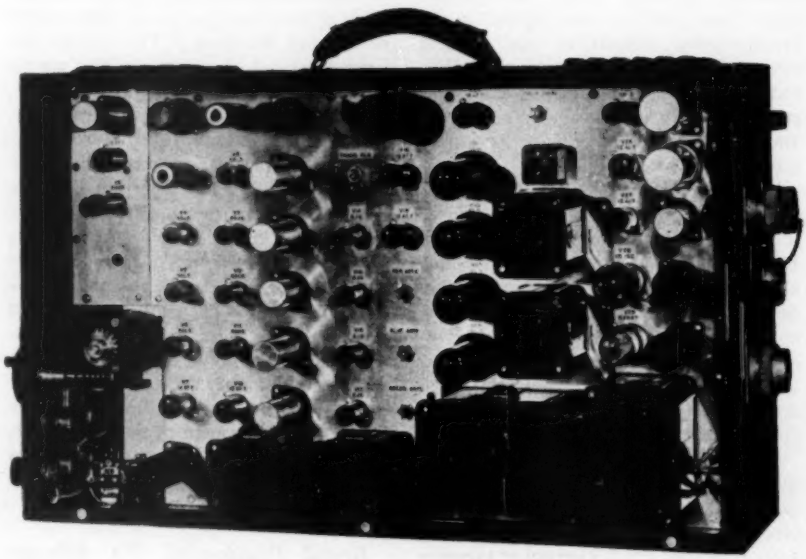


Fig. 28. Interior of unit of Fig. 27.

Fig. 29. Studio 57 stage with two color cameras.

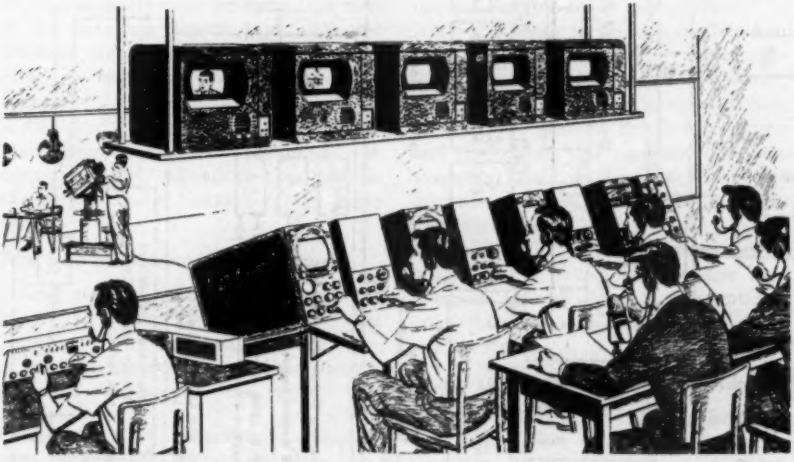


Fig. 30. Sketch of Studio 57 control room showing the director, assistant director, technical supervisor, monitoring operators and monitoring equipment.

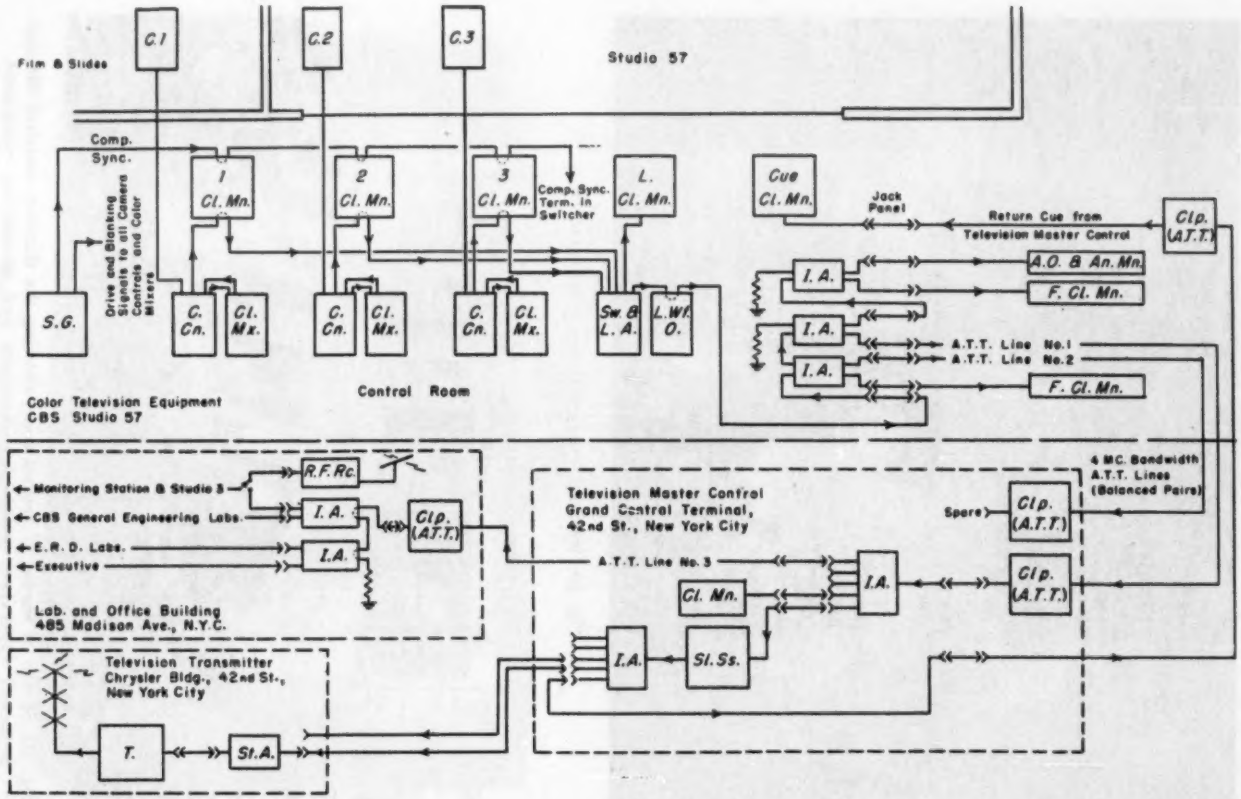

C.1
C.2
C.3
Film & Slides
Studio 57
Comp. Sync.
Drive and Blanking Signals to all Camera Controls and Color Mixers
1 Cl. Mn.
2 Cl. Mn.
3 Cl. Mn.
Comp. Sync. Term. in Switcher
L. Cl. Mn.
Cue Cl. Mn.
Jack Panel
Return Cue from Television Master Control
Clp. (A.T.T.)
S.G.
C. Cn.
Cl. Mx.
Sw. & L. A.
L. W. O.
I. A.
A.O. & An. Mn.
F. Cl. Mn.
A.T.T. Line No. 1
A.T.T. Line No. 2
Color Television Equipment CBS Studio 57
Control Room
Monitoring Station & Studio 3
CBS General Engineering Labs.
E. R. D. Labs.
Executive
R.F. Rc.
Lab. and Office Building 485 Madison Ave., N.Y.C.
Television Master Control Grand Central Terminal, 42nd St., New York City
4 MC. Bandwidth A.T.T. Lines (Balanced Pairs)
Spare
A.T.T. Line No. 3
Sl. Ss.
Television Transmitter Chrysler Bldg., 42nd St., New York City
T.
St. A.

Fig. 31. Color television signal distribution system, block diagram.

A.O.&An.Mn. = audio operator, announcer and monitor
C. = camera
C.C.N. = camera control
CL.MN. = color monitor
CL.MX. = color mixer
CLP. = clamper
COMP. = composite
F.CL.MN. = floor color monitor
I.A. = isolation amplifier
L.WF.O. = line waveform oscilloscope
L.CL.MN. = line color monitor
RC. = receiver
S.G. = sync generator
SL.SS. = selector system
SW. & L.A. = switcher and line amplifier
ST.A. = stabilizer amplifier
T. = transmitter

entire camera chain from a 60-cycle/sec source if a synchronizing signal generator originally designed for color television is used and if common cathode-filament leads and all inadequate ground leads are eliminated. As an alternative, a synchronized 144-cycle/sec motor generator can be used to power all filaments and the synchronizing generator shaping units. A 1500-w unit is adequate for a two-camera chain.

The inter-lock circuits should be so connected that the regulated supplies of the two chains can be turned on only if the separate power input for the filament transformer is energized (with either a 60- or 144-cycle/sec, 115-v source).

Identical procedures to those used in monochrome may be employed in operating and adjusting the camera control and tube voltages of the color chains.

Film and Slide Scanning Equipment

One method of color film scanning has been described in detail in this JOURNAL.[4] Another method makes use of an intermittent-type motion picture projector to project the color film through a shutter directly onto the image-orthicon photocathode.

The projector is a monochrome type used for 16-mm film at 24 frame/sec. The projector is driven by a synchronous motor and is thereby locked to the 144-cycle/sec field rate of the color system. Between the projector lens and the color camera a light shutter rotates which has a multiple of three slots. If the shutter rotates at 48 rev/sec, three slots are required, and the width of each slot is such that the duration of exposure is less than the vertical blanking time. This shutter is also driven by a phaseable synchronous motor. The proper red, blue and green color filters cover the shutter openings, and the projector and shutter disk are so phased with respect to the camera scanning that successive red, blue and green color images are flashed onto the camera tube photocathode only during vertical retrace times. The pulldown time of the projector is of short enough duration so that the film moves 24 times/sec only during portions of the active scanning period. In that period, however, the light from the projector is cut off by the opaque sections of the slotted disk.

Two methods have been used to scan color slides. One, using an image-dissector tube, has been described,[4] together with the film scanning method. In this arrangement the slide projector and its color disk replace the film scanner; the images are projected directly onto the photocathode of the dissector tube.

The second method consists simply of projecting the color slides at low light intensity directly into a conventional image orthicon-equipped color television camera.

Studio Lighting for Color Television

In general, flat lighting over the entire stage area gives best results for color television. A certain amount of modeling may be desirable, in which case ordinary spotlights are satisfactory.

[4] Bernard Erde, "Color television scanner," *Jour. SMPE*, vol. 51, pp. 351–372, Oct. 1948. This scanner uses an image-dissector tube and continuously moving film.

Fig. 32. Industrial color television equipment; camera and control console.

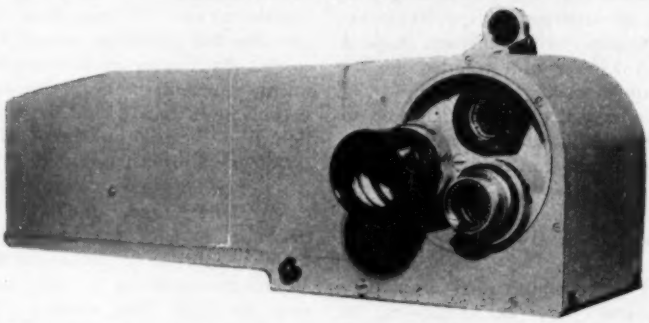


Fig. 33. Industrial color television camera, front view. Tripod not shown.

For overall flat key lighting 3500 K (white) fluorescent lighting is excellent. The advantages of this type of key lighting are that it contains no infrared, is relatively shadowless, generates little heat and is relatively efficient. The fluorescent lamps for key lighting can be operated from a standard three-phase 60-cycle/sec supply but must be connected in such a manner that all three phases are represented in any three adjacent bulbs.

Spotlights for modeling should be infrared corrected. This can be accomplished by means of one-inch strips of Aklo No. 3962 glass (or equivalent) placed in front of the spotlight. The strips prevent the Aklo filter from cracking with absorption of radiated heat.

If incandescent lighting with a color temperature of 2900 K is used, it is advisable to provide infrared filtering by using an Aklo No. 3962 (polished) glass filter between the camera lens and image-orthicon tube. Since each Aklo

filter attenuates the visual spectrum by approximately 50%, it is preferable, when possible, to employ the newly developed interference heat filters. One type already tested, known as type EK-227, passes the visual range with an efficiency of almost 90%, while the infrared energy is attentuated by 91%.*

Standard photofloods furnish satisfactory lighting for color studio use, but naturally are short lived. In most cases infrared filtering is not required with this type of lighting. Lamps used in clusters and floor strips provide an excellent source of light. These have color temperatures of approximately 3200 K and require only mild infrared correction.

As to light level requirements, experience has shown that 200 ft-c (footcandles) infrared-corrected incident light will permit sufficient stopping down of the camera lenses to provide an adequate depth of focus. On the other hand, an $f/2$ lens and 20 ft-c of corrected incident light will produce an acceptable color picture.

Figure 29 shows two color cameras in operation in CBS Studio 57. The left camera takes long shots while the camera on the right is used for close-ups.

Figure 30 is a sketch of the control room. In the upper portion are shown the color monitors, one each for the live cameras, slide projectors, film cameras, and one for monitoring the outgoing picture. The operator at the extreme left controls the audio console; the next three operators control the video. Each of these also operates a color mixer in order to assure optimum color fidelity. The remaining indicated personnel are the director, the assistant director and the technical supervisor.

Figure 31 is a block diagram of the video signal distribution system. Each camera has an associated camera control, a color mixer and a color monitor. Several color monitors are used to permit program cuing, timing and overall checking.

The outgoing signal is transmitted over video lines of the telephone company from Studio 57 at 109th Street and Fifth Avenue to TV Master Control at Grand Central Terminal in New York City. From there the signals are distributed to network stations and to the WCBS-TV television transmitter in the Chrysler Building.[5]

IV. Industrial Color Television

SINCE THE ADVENT of industrial television, its uses have expanded enormously, and with the addition of color there seems to be no limit to the number of applications it will satisfy in science, medicine, education, industry and government. Industrial equipment is essentially closed-link equipment designed with emphasis on ruggedness and reliability. Such equipment, designed by CBS, is now available and is marketed by Remington Rand under the trade name "Vericolor."

Figure 32 shows the industrial color camera with its control console. Since it is desirable to reduce camera weight and size to a minimum, the camera control equipment, synchronizing signal generator, waveform monitoring, etc., are all located in the control console. The color monitor in the console and the optical viewfinder at the camera take the place of a color viewer at the camera.

*If the infrared sensitivity of image-orthicon tubes were sufficiently low, it would be possible to dispense with infrared filters.

[5] W. R. Fraser and G. J. Badgley, "Motion picture color photography of color television images," *Jour. SMPTE*, vol. 54, pp. 735–744, June 1950. Motion picture color photography of color television images has been successfully accomplished and is described in the literature.

Fig. 34. Monochrome and industrial color television cameras.

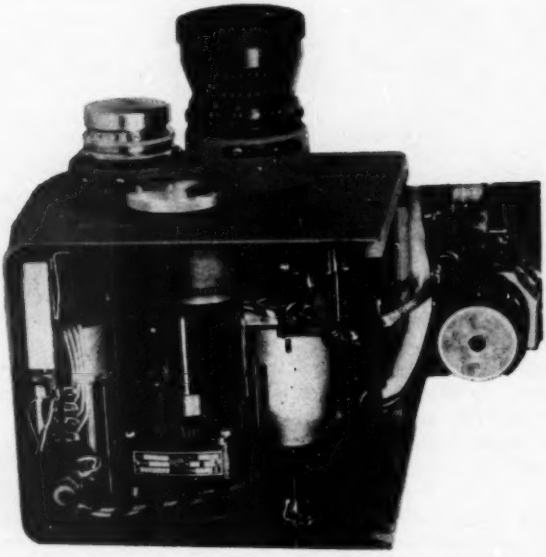


Fig. 35. Industrial color television camera with color-disk drive.

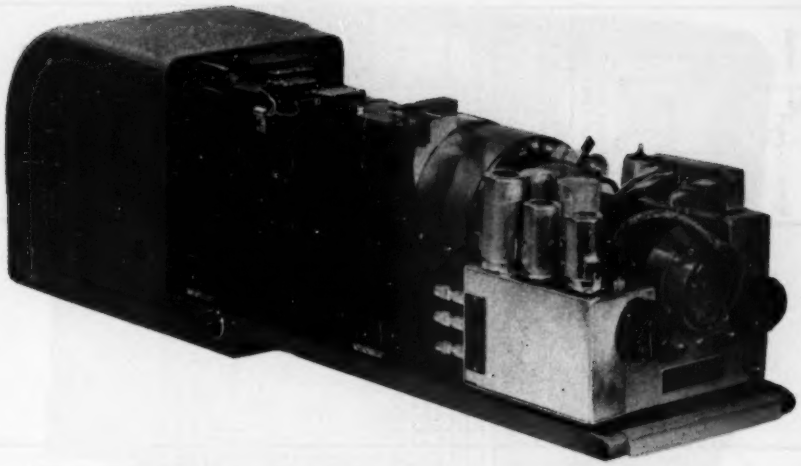


Fig. 36. Industrial color television camera with preamplifier, dynode power supply, and image orthicon focus and alignment coils.

The industrial color camera (exclusive of the tripod) weighs only 43 lb. As illustrated in Fig. 33, it is unusually compact, being only 23 in. long by 7½ in. by 7½ in. Figure 34 is a comparison photograph of the RCA monochrome television camera and the CBS industrial color television camera. Figures 35 and 36 are interior views of the industrial color television camera.

Camera focusing and lens selection are remotely controllable from the control console. Any one of three lenses in the turret may be selected by pressing the corresponding button. Full focusing range control is provided for the 83-mm and the 135-mm lenses; for the 9-in. lens two lens-shifting steps of 1-in. each are provided on the camera turret in conjunction with a remotely controlled continuous travel range of 1½ in.

A small synchronous motor operating at 1440 rpm drives the 2½-in. diameter color filter drum.

The output voltage of the camera in normal use is approximately 0.3 v peak-to-peak. This is derived from a self-contained preamplifier. The first two tubes in this unit function as normal wide-band amplifiers with a small amount of degeneration in the cathode circuits; the output stage is a conventional triode cathode follower. A compact 3-kc, 1500-v supply with its voltage divider furnishes all the voltages required by the image orthicon tube. A 25-ft cable connects the camera to the control console.

This color camera has proved to be extremely valuable for live pickup in color at low illumination levels. Acceptable color images can be obtained with only 45 ft-c of incident 3500 K fluorescent light and a lens opening of *f*/3.5. With incident light of 100 ft-c excellent picture quality is obtainable.

The Control Console

Figure 37 is a block diagram of the complete equipment. The signal leaving the color camera passes through the camera cable to the console (shown in Fig. 38) where the following functions are performed (the rear of the console is shown in Fig. 39):

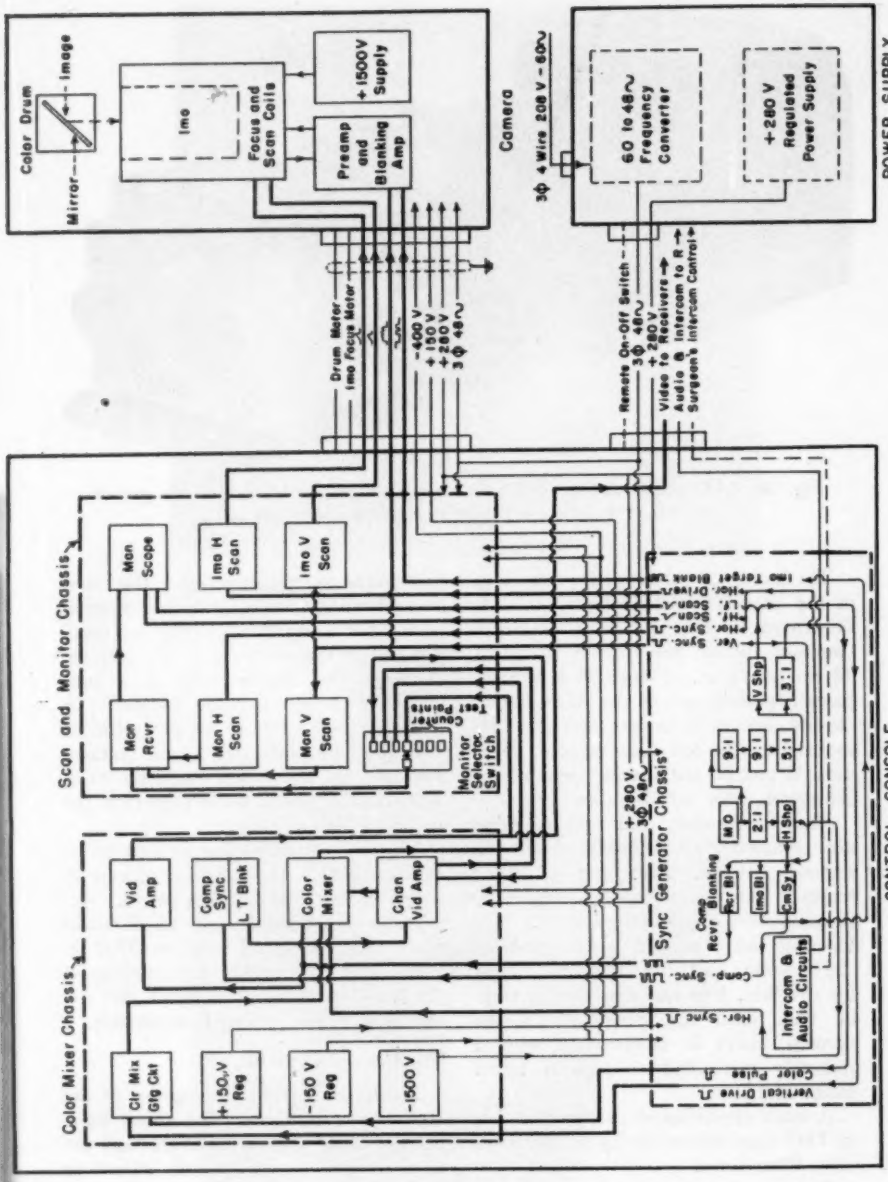


Fig. 37. Industrial color television equipment, block diagram.

Fig. 38. Industrial color television monitor console (cover closed). Note—The oscilloscope in the upper right corner shows red, blue and green signals.

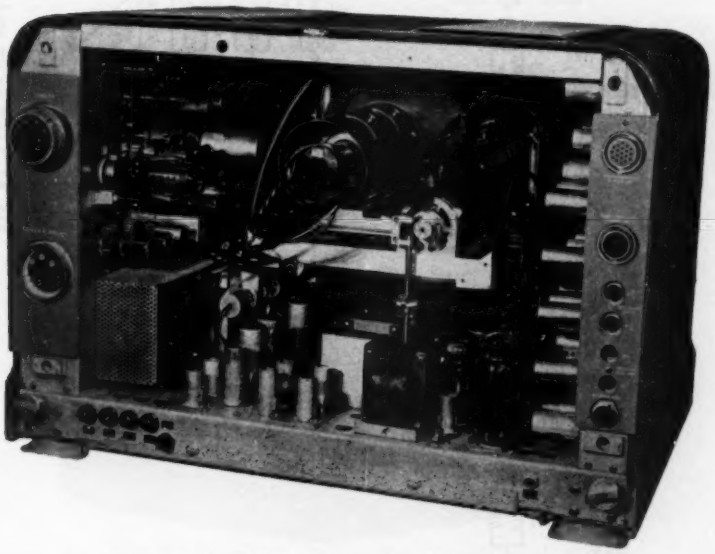


Fig. 39. Rear view of Fig. 38 showing 3-chassis construction.

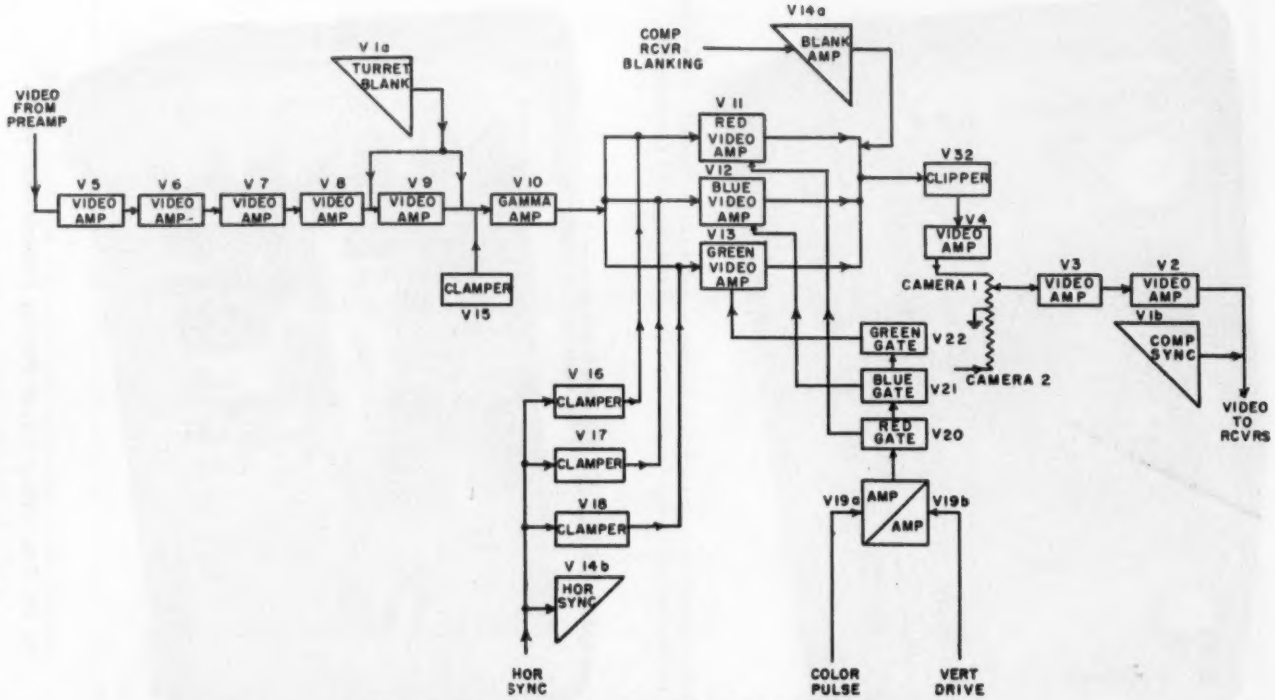


Fig. 40. Color mixer and related circuits, block diagram.

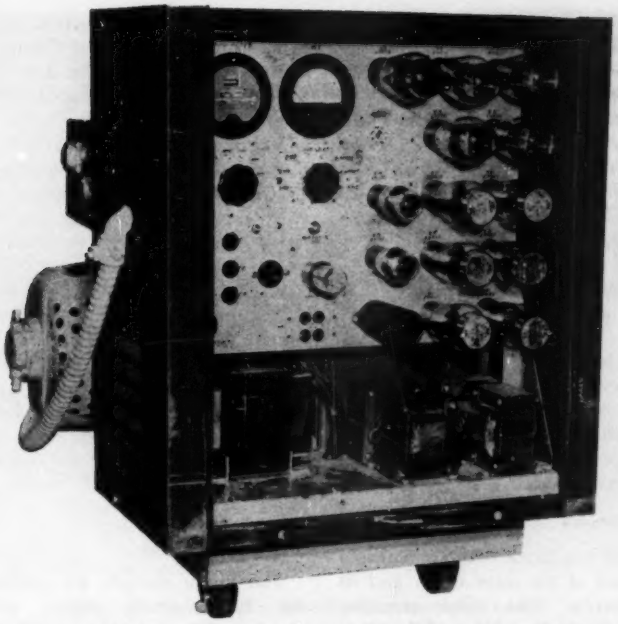


Fig. 41. Frequency converter and power supply regulator.

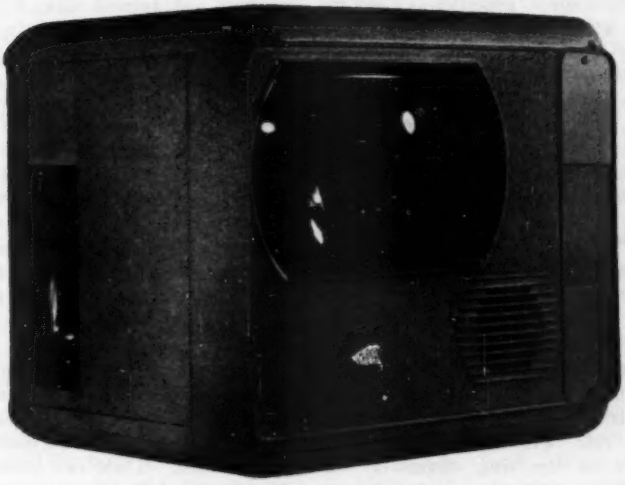


Fig. 42. Industrial color television monitor.

(1) amplification of the video signal;

(2) reinsertion of the high frequencies lost in the camera, the connecting cable, and the input circuit of the console;

(3) electrical separation of the video signals representative of the three colors in the color mixer so that each may be controlled independently as to brightness and video level (color mixer);

(4) recombining the controlled video signals;

(5) amplification and mixing of the synchronizing pulses with the video signal;

(6) remote control of camera focus;

(7) remote control of camera lens selection; signal automatically blanked during motion of the lens turret; and

(8) complete color picture monitoring of the outgoing signal.

General Circuits

Figure 40 is a block diagram showing the functions of the color mixer and its related circuits. The video amplifier consists of five tubes, V5 to V9. It is of conventional design with a bandwidth of 10 mc. A conventional equalizing circuit is located in the plate load of the first stage. Tube V1 is used to generate a blanking signal which momentarily blanks the video amplifier at V8 and V9 whenever the turret selection button is pressed. Tubes V11 to V13, inclusive, and V15 to V18, inclusive, operate as conventional clampers in maintaining the desired black level during the blanking signal period.

Color Mixer

The signal from V9 is coupled to a gamma control amplifier, the output of which is branched into three identical amplifiers. A gain control is located at the input of each of these units. Gating is performed by a rectangular wave of 1/144-second duration at the color repetition rate (48 cycle/sec) which originates in the ring circuit to be discussed later. In the circuit shown, tube V11 is the amplifier for red, V12 for blue, and V13 for green, each tube controlling only one primary color. Composite blanking, the amplitude of which may be adjusted, is superimposed on the plates of these tubes. The output is amplified and coupled into a voltage divider, which is used as an output gain control. Finally, after passing through two video amplifier stages, the video signal is mixed with the synchronizing pulses to form the final output signal.

Pulse shapes and relative phases from the gating ring circuit are shown in Fig. 25.

Sweep Circuits

The sweep circuits for both the image orthicon and the monitor color tube are of orthodox design with the exception of the special horizontal output transformers used.

Audio Equipment

The audio circuits are mounted on the synchronizing signal generator chassis. They provide amplified intercommunication between the video operator, camera man, director, and remote locations such as classrooms in other buildings. A control tube, V31B, acts as a remotely controlled switch, allowing extra earphones to be connected across the intercommunication circuit. If, for instance, a medical student watching an operation in a classroom wishes to ask a question of the surgeon in the operating room, he pushes a button located on the intercommunication headset at the color receiver. This connects the surgeon's hearing-aid-type earpiece across the intercommunication circuit. The surgeon answers the question over the regular program channel, using a miniature microphone in his mask.

The audio circuits in the console also provide amplification of the audio program. A two-channel microphone input and +8VU level balanced output are provided. These can accommodate the surgeon's microphone and two additional microphones.

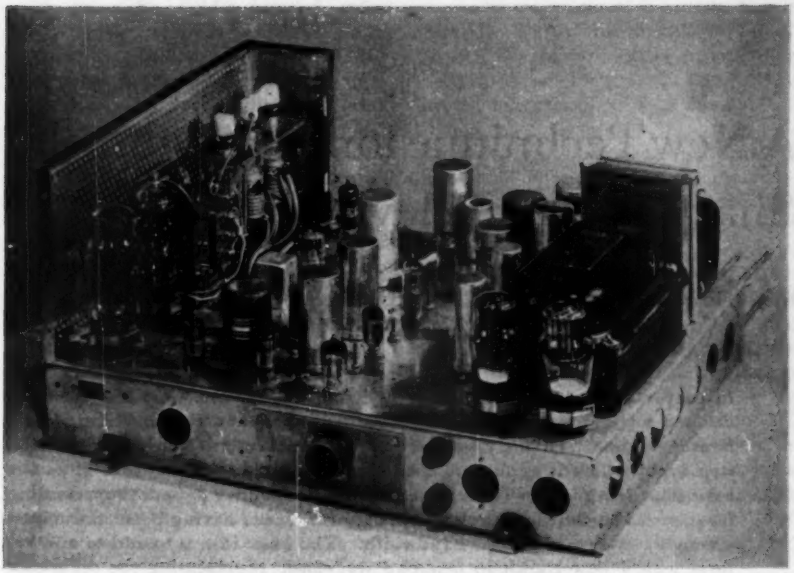


Fig. 43. Industrial color television monitor chassis.

Power and Control Circuits

To effect an overall simplification of the equipment, 48-cycle/sec power is obtained from a motor-generator set, shown in Fig. 41, operable from a 60-cycle/sec, 3-phase, 4-wire 208-v supply. Two hundred eighty volts d-c at 1 amp is obtained from a conventional regulated power supply which is mounted with the motor generator on a portable assembly.

A switch on the console remotely controls power to the entire equipment. Power for field excitation of the motor generator is applied approximately twenty seconds after the main switch has been closed by means of a time-delay relay.

Maintenance and operational checks are facilitated by both a meter on the regulated supply and test connections at the motor generator.

Color Monitor

Figure 42 is a photograph of a color television industrial monitor showing an intercommunication handset recessed at the left rear of the console. Figure 43 shows the chassis construction and arrangement of this unit.

Acknowledgment. This paper in many ways is intended as a tribute to that handful of tireless and enthusiastic workers, namely, the people of the CBS Laboratories Division, who helped to develop the CBS color television system from its modest start in the spring of 1940 up to the time it became the national color television standard after gruelling hearings and exhaustive comparative tests.

To the management of CBS we express our appreciation for their never-failing faith in our work. Without their generous and courageous support this new industry would not have been born.

A New Technique for Improving the Sharpness of Television Pictures

By PETER C. GOLDMARK and JOHN M. HOLLYWOOD

In conjunction with the CBS color television system a method has been developed for improving the apparent picture definition, called "crispening." It uses nonlinear circuitry to decrease the apparent rise time of an isolated step input which is applied to a bandwidth limited system. This gives the color television pictures (with the exception of repetitive patterns representing frequencies beyond system cutoff) the appearance of having been transmitted through a system of greater bandwidth. The basic idea is to add to a waveform with a slow transition a second waveform, representing the difference between the desired waveform and the original waveform.

A simple circuit is described which utilizes nonlinear means for reforming the roughly triangular differential of the step signal into a narrower "spike" roughly triangular in shape which is superimposed on the original waveform to obtain a response corresponding to about half the original rise time. Various crispening circuits have been designed for specific applications and will be discussed in more detail.

WHEN VIEWING television pictures, the observer trying to follow the action has little time to delve into any particular area of the picture and focus his attention on any one fine detail, unless the detail is stationary and of some special importance. Nevertheless, an observer will always be able to tell whether a picture is sharp or fuzzy. Experience has shown that pictures appearing sharp do not necessarily contain extremely small objects, objects so small that they require the ultimate bandwidth of the system. It is the sharpness of objects almost always greater than one or two picture elements which matters, and the purpose of this paper is to report on a method rendering outlines of such objects sharper, corresponding to, roughly, double the bandwidth.

The overall impression of such a picture with sharper outlines can be called crisp. The special circuits capable of obtaining such an appearance with a limited bandwidth, have been called crispening circuits.

A contribution submitted September 4, 1951, by Peter C. Goldmark and John M. Hollywood, Laboratories Division, Columbia Broadcasting System, Inc., 485 Madison Ave., New York 22, N.Y. This paper is being published simultaneously in the *Proceedings of the I.R.E.*

In the CBS field-sequential color television system the horizontal resolution is a little over half that of standard monochrome television. In the technique to be described, outlines of objects wider than a single picture element can be made as sharp as the maximum sharpness possible in standard monochrome pictures as far as the horizontal direction is concerned. Naturally, due to the 4-mc video limitation, the smallest object which the color system now can depict accurately in a horizontal direction is equivalent, roughly, to two monochrome picture elements. It is seldom, however, that the overall sharpness of a picture depends on being able to depict such small objects accurately. In fact, in such cases, by the choice of proper lens and camera technique, an object when increased a little over 50% in linear dimension would have the same definition as in the monochrome system.*

At the outset it should be pointed out that crispening has nothing in common with peaking, pre-emphasis or aperture-correction methods heretofore employed for high-frequency pictorial compensation, as will be shown in this paper.

The relation between bandwidth of a linear system and rise time for a suddenly applied voltage input step is well known. This has probably caused the casual investigator to dismiss the problem of improving rise time as insoluble. However, the well-known relations are confined to linear systems. Improvement of the rise time is possible by means of nonlinear operations performed on waveforms associated with a system of limited bandwidth. Such operations cannot be expected to yield a system output if the system input is a sinusoidal waveform of frequency higher than the limited bandwidth will pass. No new information can be produced at the output, but the original bandwidth-limited information can be changed in its nature.

In the case of television pictures, high-detail information is, for the most part, of the nature of isolated steps, and only rarely of a repeated nature approximating a steady-state waveform made up of frequency components above the system bandwidth limit. The "crispening" method described in this paper uses nonlinear circuitry to modify the nature of the isolated step response of bandwidth-limited systems. This gives television pictures the appearance of having been transmitted through a system of greater bandwidth than is actually used, except for omission of such high-frequency repetitive patterns, and inability to resolve closely spaced fine lines.

Basic Approach

The basic idea is to attempt to add to a waveform having a slow transition a second waveform which represents the difference between the waveform desired and the waveform originally present. Figure 1(a) shows an idealized waveform of slow transition, and Fig. 1(b) shows a family of curves depicting possible waveforms, any one of which can be added to it to make the resultant have an infinitely fast transition (see corresponding curve in Fig. 1(c)). As a less ambitious illustration, Fig. 2(b) shows a family of curves depicting possible waveforms which can be added to that of Fig. 2(a) to make the resultant have twice the original transition rate (Fig. 2(c)). Any of the three waveforms in Fig. 2(c) can be obtained from that of Fig. 2(a) by the use of the corresponding correction waveform in Fig. 2(b). It will be noticed that the correction waveform of Fig. 2(b) can be of a simple shape, for example, either a negative or positive triangular spike.

* The arithmetic mean between the number of alternate bright and dark lines in the horizontal and vertical directions for which total loss of definition occurs is a little over 50% greater for monochrome than for color. (The ratio of the frame frequencies is 2.4:1, so that a ratio of linear dimensions of $\sqrt{2.4}$ or 1.55:1 would give equal definition.)

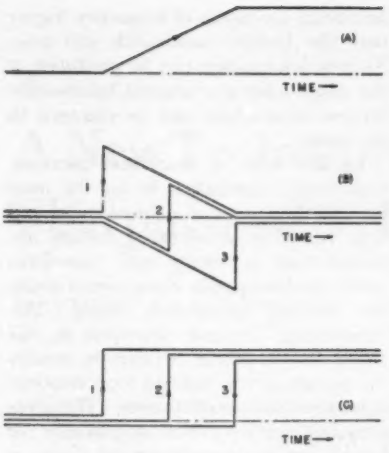


Fig. 1. (a) Waveform of slow transition rate; (b) added waveform for fast transition rate; (c) resultant waveform after addition.

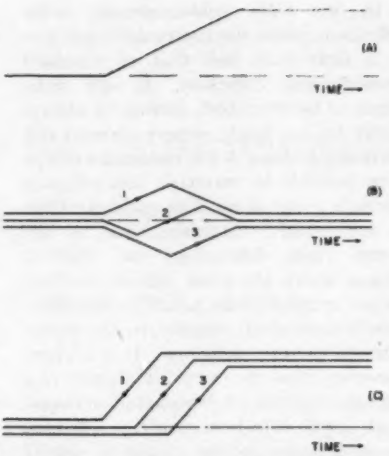


Fig. 2. (a) Waveform of slow transition rate; (b) added waveform for twice transition rate; (c) resultant waveform after addition.

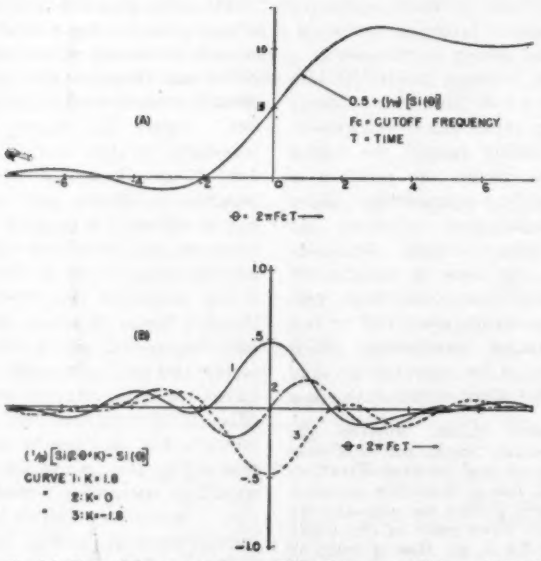


Fig. 3. (a) Transition waveform of ideal low-pass filter; (b) added waveform for twice transition rate.

In practice, the type of waveform to be corrected would be more like that of Fig. 3(a), the step response of an ideal low-pass filter. Any one of the curves of Fig. 3(b) represents the correcting waveform required to double the transition rate. Thus the resultant will duplicate the step response of a filter of twice the cutoff frequency. The correcting waveform could be approximated by a negative or positive triangular spike.

The negative or positive differential of the original waveform can serve as a useful approximation. Adding or subtracting the differential increases the transition rate, but may be accompanied by "overshoots," which sometimes are undesirable. This is to be expected since no nonlinear elements are involved. Looking at it from the corrective waveform standpoint, the added spike is wider than that most desirable.

If the differential of the original waveform is modified, making it less wide by using a nonlinear power law device (for example, squaring its amplitude for both polarities), a correcting waveform may be obtained, which gives a steepened resultant free from overshoot. But this holds rigorously for only one transition amplitude. If the differential of the original waveform is made less wide by clipping, passing only the peaks of the differential waveform, a correcting waveform may be obtained, which also gives a steepened resultant free from overshoot or undershoot. This result also holds true rigorously for only one transition amplitude, unless the clipping action can be made to follow any change in amplitude.

A shortened spike can be obtained from the differential if the latter is made available as the voltage from a low-impedance source feeding a rectifier having a load consisting of resistance and capacitance in parallel, and the current through the rectifier is used as the output spike. The spike amplitude is then nearly proportional to the transition

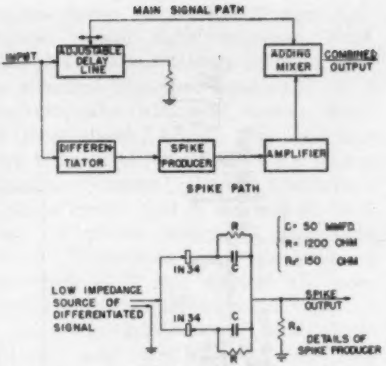


Fig. 4. Block diagram of simple crispening circuit.

amplitude. This method is employed in a practical "crispener" to be described.

In Appendix A the basic idea will be explored further to show that any degree of steepness correction in isolated transient steps is possible.

Applications

Figure 4 is a block diagram of a simple crispening circuit based on the above method. To insure that a spike can be centered halfway up the slope of the uncorrected waveform, an adjustable delay is included in the main signal path. The frequency response for circuits associated with the main signal path need only be good enough to accommodate all frequencies initially present in the input signal. The spike path after the spike has been formed, and the circuits handling the combined output, should preferably have at least twice the bandwidth of the input signal. Such an arrangement has been used for experimental observations and also has been tested in conjunction with color television receivers.

In the course of demonstrations of color television originating in New York studios and being shown in cities as far as Chicago, it was desired to apply a similar arrangement to the improvement

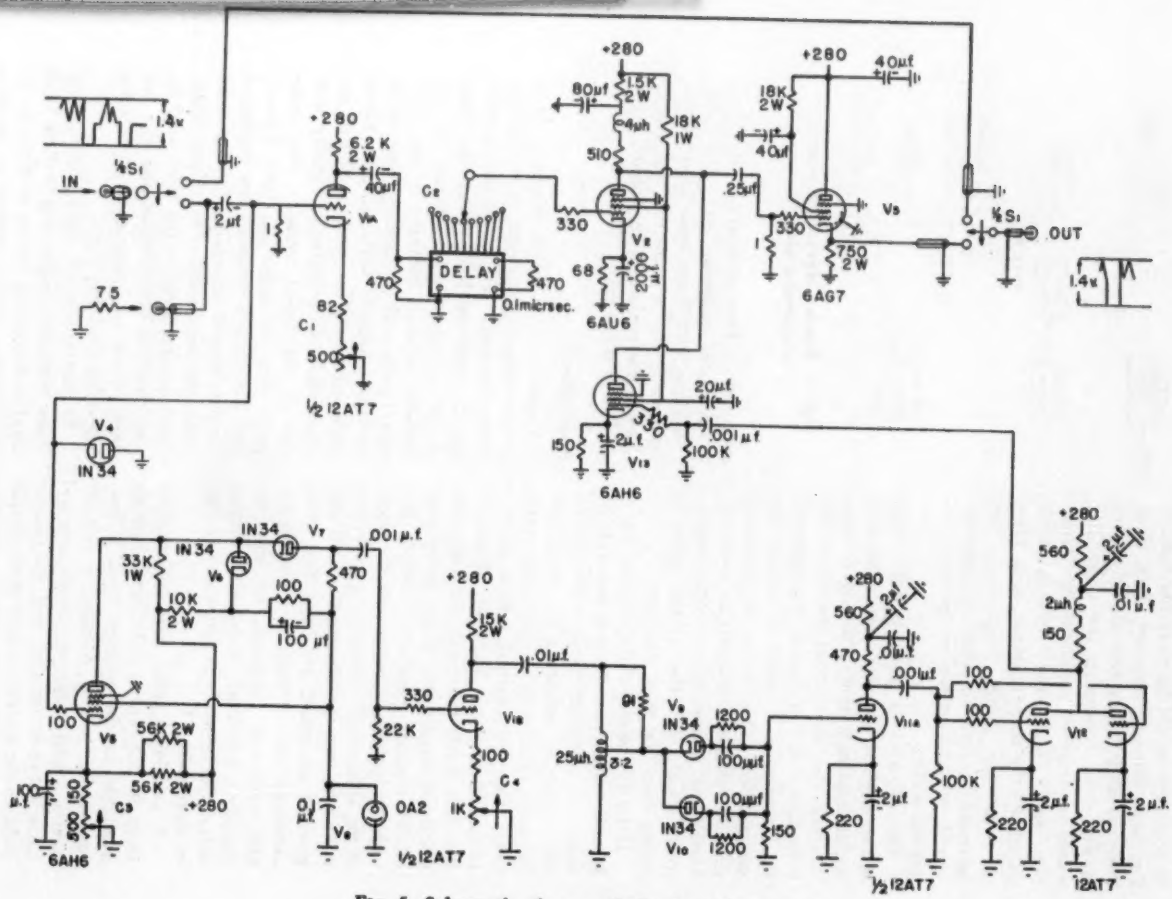


Fig. 5. Schematic of a practical crispening circuit.

of pictures transmitted by coaxial cable for which the cutoff frequency was about 2.7 mc. Several units were built for this purpose, of a sufficiently versatile nature to warrant giving a detailed description.

Figure 5 is the schematic diagram of this special crispener. It handles an input of 1.4 v peak-to-peak including synchronizing pulses, from a 75-ohm line. The output level and polarity into a 75-ohm line are the same as for the input. The circuits for the main signal path and combined output (V_1, V_2, V_3) are flat within 1 db to 6 mc, and 3 db down at 9 mc. The circuits associated with the spike path and combined output after spike production (V_{11a}, V_{12}, V_{13}, V_3) are flat within 1 db to 8 mc, and 3 db down at 10.5 mc. The main signal path includes a control, C_1, to adjust the overall gain to unity, and a control, C_2, to adjust delay in the main signal path, to allow shifting transitions so that the spike falls on the optimum part of the slope. If spikes are not injected, the overall output is essentially the same as the input except for delay.

Spikes for either direction of transition are produced by the crystal rectifiers V_9 and V_{10} with their associated *RC* loads. The input to the spike-producing rectifiers is essentially the differential of the input signal, obtained at low impedance by using a transformer which also serves as the differentiating inductive load for V_{11B}. The spike duration is mainly controlled by the *RC* values in series with V_9 and V_{10}, although also influenced by the frequency responses of circuits both preceding and following the spike formation. The spike path after spike formation includes the tubes V_{11A}, V_{12}, and V_{13}; the plate of the latter is in parallel with the plate of V_2 in the main signal path, at which point the spike is added on to the transition and the combined output fed to the output cathode follower V_3. No control is provided for spike duration. The *RC* values shown are used for "crispening" either coaxial cable television transmissions or transmissions received from a standard television transmitter by a representative television receiver, down 3 db at about 3.4 mc. The capacitors are reduced to 50 $\mu\mu$f when the unit is used to "crispen" pictures transmitted over a circuit that is down 3 db at 4 mc (telephone company microwave link). Control of spike amplitude is provided by a gain control, C_4, associated with the differentiator V_{11B}.

In some applications, these "crispeners" were used following stabilizing amplifiers, to which a television signal of low bandwidth and long rise time was applied. The stabilizing amplifiers reshaped the synchronizing pulses to have a much faster rise time, but left the slow rise time of the video signal unchanged. The crispening unit then required a clipper to cut out the synchronizing pulses before producing spikes; otherwise undesirably large spikes were caused by the synchronizing pulses. V_5, V_6, V_7 and V_8 constitute this clipper, the clipping level being adjusted by the control C_3. Naturally, this precaution is necessary only when the signals thus treated are intended for broadcast.

In future applications, a crispening circuit will be built into a suitable stabilizing amplifier, of the type that provides one path for video alone—to which crispening will be applied—and a separate path for reshaped synchronizing pulses alone. It is expected that this will require the addition of six miniature tube envelopes to the stabilizing amplifier, a net economy for applications requiring a stabilizing amplifier in conjunction with a crispening unit.

Results Obtained

In demonstrations of field sequential color television in cities remote from New York, some of which involved transmissions via standard telephone company coaxial-cable circuits, use of

Fig. 6. Picture transmitted with 4.5-mc cutoff frequency, uncrispened.

Fig. 7. Picture transmitted with 4.5-mc cutoff frequency, crispened.

Fig. 8. Picture transmitted with system flat to 10 mc, uncrispened.

"crispeners" gave a definitely more pleasing picture.

Figures 6, 7 and 8 show, respectively, field-sequential color television pictures of FCC approved standards transmitted with maximum bandwidth of 4.5 mc (3 db at 3.2 mc) uncrispened, the same crispened, and with a system flat to 10 mc uncrispened, as photographed from the screen of an industrial receiver. Figures 9, 10 and 11 show the reproduction of a test pattern under the same circumstances. Figure 12 shows the response frequency of the filter used to limit bandwidth to 4.5 mc. It can be seen that for the narrow bandwidth, even though the fine-detail part of the wedge is not reproduced, the part of the wedge that is reproduced is more clean-cut when crispening is employed; and in the photographs of picture material, the edges of objects are delineated in a manner that compares favorably with the 10-mc uncrispened picture.

Figure 13 is an oscilloscope picture showing superimposed the normal and crispened waveforms obtained from input steps of different amplitudes where the input steps have been passed through a low-pass filter of 2-mc bandwidth to the 3-db point.* The improvement due to crispening is clearly apparent, as well as the extent to which the "crispener" described achieves a correction independent of transition amplitude.

Figure 14, taken under the same conditions as those of Fig. 13, shows the normal and crispened waveforms obtained when a square input pulse of $\frac{1}{8}$-μsec duration is applied. This would give, theoretically, a peak of 48% of the asymptotic response to a long pulse. Doubling the bandwidth would raise

* The choice of a relatively low cutoff frequency (2 mc to the 3 db point) for the input signal makes the waveforms resulting from crispening less subject to modification by bandwidth limitations in the circuits that follow the crispening operation. This choice also represents an approximation to operations with coaxial-cable circuits.

the peak amplitude to 87%, an increase of 80%. Figure 14 shows that the amplitude does not increase appreciably, but that the pulse shape is improved, when crispening is applied. Isolated fine-line detail, therefore, is improved in quality by crispening but not brought up to the same intensity as with a true increase in bandwidth. Subjectively, however, the improved shape seems to give the impression of somewhat improved fine-line intensity also.

Home Receivers

An interesting application of crispening is in the improvement of color television picture appearance for home receivers. Considerable simplification is possible as compared to the system of Fig. 5. An experimental arrangement that has been used is shown in Fig. 15. Two double triodes and two crystal rectifiers are added to a conventional receiver. The connections to the added circuit are indicated by dotted lines.

The spikes are produced in a manner similar to that already described for the circuit of Fig. 5. After amplification, the spike is injected into the cathode of the picture tube while the main signal path leads to the grid in the usual manner. If more delay is needed in the main signal path as compared to the spike path, the inductance network that compensates the high-frequency response of the video output coupling arrangement can be modified, making it into a more extended low-pass filter circuit. The only control shown is for adjustment of spike amplitude.

This particular receiver required only a small voltage range to modulate the picture tube. If more swing were required, a power output stage might be required for the spike path. To avoid the need for a power stage, an alternative arrangement could utilize a similar chain of stages for crispening, receiving input from the grid of a low-level video stage, and feeding spike output to the output of the same stage. Relative delay adjustment could be made by modifying

Fig. 9. Test pattern transmitted with 4.5-mc cutoff frequency, uncrispened.

Fig. 10. Test pattern, transmitted with 4.5-mc cutoff frequency, crispened.

Fig. 11. Test pattern, transmitted with system flat to 10 mc, uncrispened.

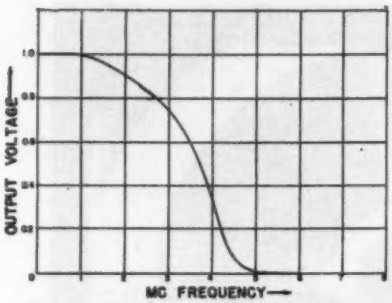


Fig. 12. Response frequency characteristic of a filter of 4.5-mc cutoff frequency.

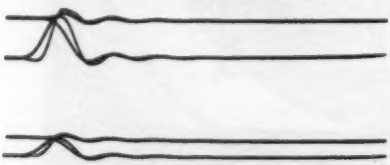


Fig. 13. Normal and crispened step waveforms for a system of 2-mc bandwidth to the 3-db point.

Fig. 14. Normal and crispened ⅛-μsec pulse waveforms for a system of 2-mc bandwidth to the 3-db point.

either the input or output coupling network for the low-level stage.

Other Applications

Other applications of the crispening principle may occur to the reader. One application of some interest is in the improvement of the appearance of recorded television transmissions. Crispening can be employed to obtain better overall sharpness at any point in the system following the film scanner, prior to the transmitter. For this application some control of spike duration would be desirable, in addition to control of spike amplitude.

Some Special Considerations

The effect of crispening circuits on the signal-to-noise ratio may be of importance if appreciable noise is present in the picture, either as a result of noise initially present before transmission or additional noise introduced at the receiver. The crispening circuit of Fig. 5 has been found to increase the level of random noise by roughly 50% which is comparable to the increase in noise that would have resulted from doubling the bandwidth. No exact analysis of the theoretical effect of crispening on signal-to-noise ratio has been carried out; the results would differ depending on the empirical circuitry employed to obtain a practical crispener.

The fact that any practical crispening arrangement devised represents an empirical design solution introduces a general difficulty in evaluating as a class the performance of crispening circuits for impressed waveforms of a complex nature. The elegant mathematical analyses such as are customary for circuits composed of linear elements cannot be used, since there is no unique solution to the circuit design problem. This is not to say that mathematics cannot be applied to any particular circuit; it can, although the nonlinear behavior introduces difficulty.

"Frequency response" is a meaningless term for nonlinear circuits, since for a given input frequency, the output consists not only of the original frequency, but also an infinite series of harmonics, the amplitudes and phases of which vary in different manners with change of the input frequency.

It might be thought that crispening circuits may increase the transition rate to that corresponding to a greater bandwidth than is actually used, not only for sharp brightness transitions in the picture material, corresponding to infinite bandwidth, but also for less sharp brightness transitions corresponding to the bandwidth actually used. A system behaving like an ideal low-pass filter with abrupt cutoff at 4 mc would give identical responses for an infinitely steep brightness transition or one having a waveform

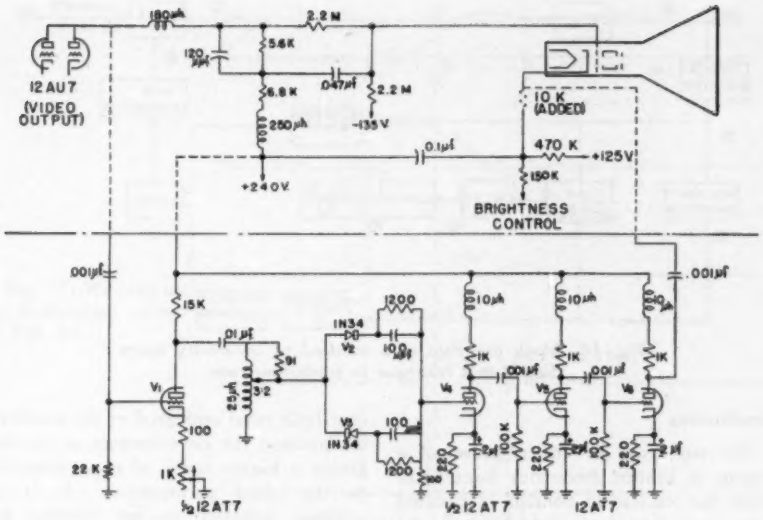


Fig. 15. Crispening circuit for a television receiver.

like the step response of an ideal filter of 4-mc cutoff. The latter response would be the same as that of an infinitely steep transition applied to two ideal low-pass filters in cascade.

Actually, when pictures are scanned, the transition waveforms are not of this shape. They are equivalent to the step response of a circuit having a gradual, rather than an abrupt frequency cutoff. If cascaded with an ideal low-pass filter of 4-mc cutoff, the overall frequency response falls off gradually up to the 4-mc limit; the amount of rounding that occurs before the abrupt drop at 4 mc depends on the steepness of the original transition. The steepness of the system response, therefore, also varies with the original steepness. When crispening is applied, as with the circuits of Figs. 4 and 5, which add a spike of amplitude and duration dependent upon the steepness of the applied transition, the overall response slope also varies with that of the original transition. It is true that the degree of sharpness may not be as faithfully reproduced as with an uncrispened system flat to 8 mc. This is due to a crispened 4-mc system having a tendency to introduce a little too much sharpness on transitions having an initial slope corresponding to that of the step response of a low-pass filter of 4- to 8-mc cutoff.

This imperfection is not appreciable in practice, since it occurs only on marginal degrees of sharpness in the picture being televised, and is outweighed by the advantage of better response sharpness on sharp transitions. Most objects appear either sharp or rounded; in cases where original sharpness is in the marginal region corresponding to step response of a low-pass filter of 4- to 8-mc cutoff, the degree of sharpness is usually of no significance to the observer in identifying the object or appreciating its nature. It is of importance that an initially sharp transition should look sharp. That the imperfection is not apparent is evidenced by the overwhelming preference of observers for pictures with crispening as against pictures without crispening.

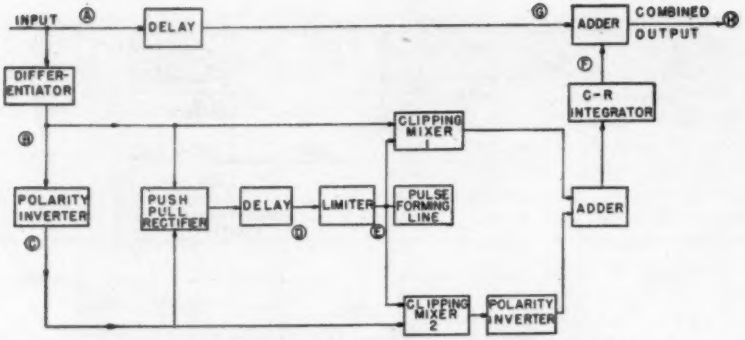


Fig. 16. Block diagram of a method of obtaining more than 2 to 1 increase in transition rate.

Conclusions

The rise time for the response of a system of limited frequency bandwidth when the excitation consists of isolated steps can be decreased beyond the theoretical limit for a linear system by utilizing nonlinear circuit elements following the point of bandwidth limitation.

"Crispening circuits" based on this principle can be designed and used to effect a significant improvement in the CBS color television pictures transmitted through a system with bandwidth limitations.

Such "crispening circuits" may have other useful applications.

Acknowledgments

Credit is due to members of the Columbia Broadcasting System engineering research department who have taken part in this development, in particular to J. J. Reeves who participated in the early experimental work and contributed many valuable suggestions.

Appendix A. More Elaborate Circuits

The relatively simple correction circuit of Fig. 4 is based upon the fact that the waveform to be added to the original to obtain a 2:1 increase in slope steepness is roughly of triangular shape and can be approximated by the output of simple circuits. Such circuits were so effective that little need appeared at the moment for pushing the development of circuits giving a higher order of approximation to the ideal performance. It is of interest, however, to see whether an increase of steepness substantially greater than 2:1 is possible.

One approach is to use for the correcting waveform, a nonsymmetrical triangle generated by integration of a short-duration pulse, modulating this pulse in accordance with the amplitude of the differential of the transition, and initiating the pulse by the passage of the differential waveform above a small fixed level. Both directions of transition must be accommodated, which introduces further complexity. The block diagram of Fig. 16 shows one method. The waveforms present at various points in this system are given in Fig. 17.

In all waveforms of Fig. 17, the solid lines represent an upward transition at the input, and the dotted lines a downward transition. The input signal is shown at A and its differential at B, or after polarity inversion at C. The push-pull rectifier, regardless of transition direction, produces a unidirectional output. This output, shaped like the magnitude of the differential, is used to produce a short pulse, timed to occur near the start of the input transition. For example, feeding the output into a

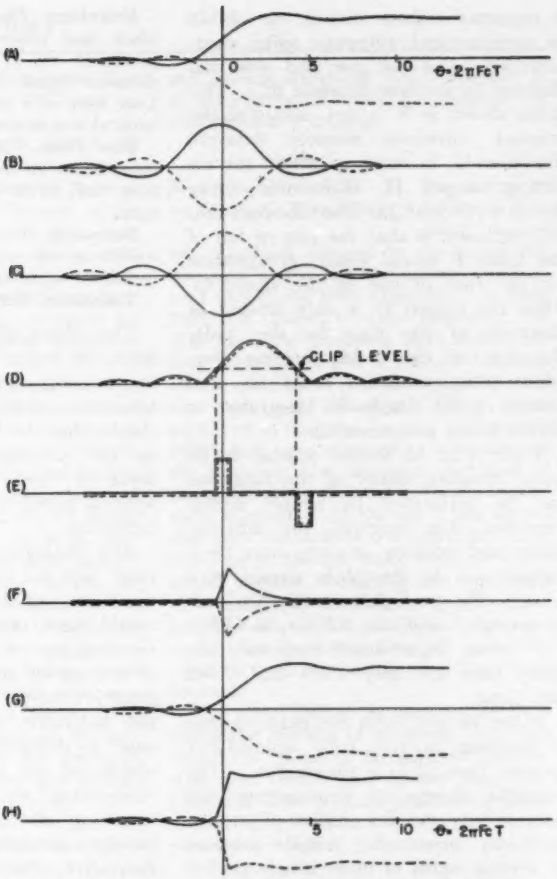


Fig. 17. Waveforms at designated points of Fig. 16.

limiter and short pulse-forming line, the waveform of E is produced. The positive pulse can be retained and the negative pulse that follows discarded by clipping in the "clipping mixers." The pulse amplitude and timing is almost independent of the transition amplitude if the level at the limiter is well above the clipping level. In order to center the positive pulse in the middle of the differential waveform, B, the input to the limiter is delayed as shown in D. The time delay shown is $(1/\pi F_c)$ where F_c is the cutoff frequency corresponding to the waveform A.

The clipping mixers modulate the pulse by the magnitude of the differential. Two are provided so as to handle both transition directions; one or the other yields an output. For an upward transition, the differential, B, modulates the pulse passing through clipping mixer 1. For a downward transition, the inverted differential C modulates the pulse passing through clipping mixer 2, which pulse is then inverted in polarity. In this way, a pulse is obtained at the adder which follows the transition amplitude and polarity, but is very short. The short pulse is then integrated by

a capacitor–resistor circuit, to obtain an asymmetrical triangular spike, characterized by a fast rise and slow fall dictated by the time constant *RC*. This spike, shown at F, is then added to the original waveform suitably delayed, shown at G, in order to obtain the resulting output H. The time delay shown is $(0.45/\pi F_c)$. The time constant, *RC*, is chosen so that the rate of fall of the spike F would nearly compensate for the rate of rise of the signal G. Thus the output H is only limited in shortness of rise time by the pulse duration of the pulse forming line. More complex means could be used instead of the simple *RC* integrator, to obtain better compensation.

While Fig. 16 would appear to be quite complex, many of the functions can be performed by simple circuit elements. For example, the differentiator and polarity inverter may be a tapped coil in the plate circuit of a triode; the push-pull rectifier, a pair of crystals; and the limiter, a 6BN6. For 3.4-mc input cutoff frequency the delay lines are only 0.094 and 0.042 μsec long.

It can be seen from this example that a decrease in rise time appreciably greater than 2:1 is obtainable. The example chosen to demonstrate this point is only one of a number of possible methods; presumably simpler schemes or arrangements of more nearly perfect performance could be devised.

Appendix B. Glossary of Terms

The glossary below gives the meaning of certain terms as used in this paper.

Crispening. Decreasing rise time for isolated step inputs by means of nonlinear circuits.

Crispness. In a picture, the degree to which edges of large objects approach discontinuous changes in brightness. For television waveforms this might be measured as the ratio of active horizontal trace time to the rise time for an isolated step input.

Definition. The number of alternate black and white lines that can be reproduced by a television system in a distance equal to the picture height. Used here as a single quantity combining vertical and horizontal definition.

Rise Time. The time required for the response to an isolated step input to rise from 10% to 90% of the ultimate amplitude.

Steepness. The maximum slope of a waveform of unit ultimate amplitude measured in inverse time.

Transition Rate. Inverse of rise time.

The above definitions are given to assist the reader and are not suggested as standard nomenclature. There is, however, a growing need for a nomenclature that can be used interchangeably in the photographic and electronic fields, in view of the increasingly close relation between the film and television industries.

The photographic concept of "sharpness" was not used in place of "crispness" as used here because, firstly, it would have required translation from the language of inverse distance to that of time ratio; and secondly, the photographic concept deals with the maximum first derivative of a curve, like "steepness" as defined above. The arbitrary nature of the curves obtainable with "crispening" makes the use of a concept involving rise time preferable to a concept involving the maximum first derivative, which could be large without having a satisfactory curve shape. Another photographic concept, "turbidity," involving the second derivative, was not used here for similar reasons. Attempts have been made* to evaluate the subjective impressions obtained from a curve of a given shape, but these were not utilized since a concept of "crispness" in terms of the generally accepted and readily described "rise time" seemed adequate for the purposes of this paper.

* A. V. Bedford and G. L. Fredendall, "Analysis, synthesis, and evaluation of the transient response of television apparatus," *Proc. IRE*, vol. 30, pp. 440–457; Oct. 1942.

Engineering Activities

Film Dimensions Committee The Committee met in May 1951 and in the absence of its Chairman, Dr. E. K. Carver, Dr. A. C. Robertson presided.

The main discussion centered around the problem raised by the decrease in the shrinkage characteristic of the film base over the years. In order to obtain optimum printing results now, negative film must have a pitch somewhat less than presently stipulated in the Standard for cine negative (PH22.34) under dimension B.

This then requires revision of the Standard. Two viewpoints were expressed as to how to proceed: (1) revise the Standard after sufficient data is available to standardize the cutting and perforating dimensions *at the time of use*, rather than at the time of manufacture; or (2) merely change dimensions B and L to a short pitch dimension in accord with present (but nonstandard) practices. It was indicated that the first procedure would require at least three years whereas the latter, possibly less than a year. Although it was generally felt that the first approach was more desirable, the other was considered a practical stopgap measure. It was, therefore, agreed to combine the two, preparing the groundwork for the long-range project while revising the present Standard for immediate use.

In addition, the problems involved in the use of film for computers were aired and several standards were reviewed as to their potential value for proposal as international standards.

Sound Subcommittee on Magnetic Recording The status of the three Proposed American Standards initiated by the group was discussed at the last Committee meeting, held during the 69th Convention in May 1951 and chaired by Glen Dimmick. At that time, the proposals were before the Standards Committee which was balloting on the question of preliminary publication for trial and comment. (They were published in the July *Journal*.) Comments which had been received in the course of the balloting were analyzed and most of the meeting was devoted to improving the three Proposals. In the end it was agreed that early publication was more important than minor, though valid, revisions which would require redrafting the Standards and additional Committee approval via letter ballots. The indicated changes could then be made after all comments resulting from trial publication have been received.

The remainder of the meeting revolved about the drafting of Magnetic Test Film Standards, primarily for azimuth and frequency of 16-mm and 35-mm film. Mr. Dimmick is to prepare preliminary drafts and circulate them to the Committee for comments.—H.K.

BOOK REVIEWS

Elements of Television Systems

By George E. Anner. Published (1951) by Prentice-Hall, 70 Fifth Ave., New York 11. i-xii + 760 pp. + 11 pp. appendix + 18 pp. problems + 13 pp. index. 400 illus. $5^1/_2 \times 8^1/_2$ in. Price $10.35.

Even with the postwar commercialization of television and the most generous oversupply of technical books, there has been no book that could satisfy the need for a genuine television engineering text. For the service technician there are so many books that they crowd the test equipment off his shelves; there is even a television encyclopedia on the service-technical level. But until the publication of Prof. Anner's volume, there has not been a thorough, rigorous engineering treatment of television.

For this reason alone, *Elements of Television Systems* is an important book. It is written by an eminently qualified person, for George Anner, as Assistant Professor of Electrical Engineering at New York University, has for three years held television courses at both graduate and

undergraduate levels and, during 1946–47, gave a special course in television for technicians at Columbia Broadcasting System. While at CBS he spent considerable time with operating personnel and equipment in studios and master control room, and at the transmitter.

The welcome novelty of Prof. Anner's approach is that he does not follow the custom of simply explaining the American system of television broadcasting. He treats television as a technical subject like any other, and begins at the correct place—the beginning—with the primary philosophy of translating a picture into an electrical signal, which is a single-valued function of time. Exploring the various methods of doing so, he explains why a certain system is the logical one, still in terms of methods and not of number of lines or frames.

The entire first section of the book deals with closed-circuit systems. This allows the distracting factors of standards details for a particular system and the irrelevant question of r-f transmission to be put aside so that the study is stripped to fundamentals. The figures governing critical flicker frequency for a cathode-ray tube, for example, are examined, so that the reader may use them as design criteria or use them to understand the reasons for broadcast standards, whichever his interest. The operation of the cathode-ray tubes is examined in detail and formulas for such items as electron velocity are derived. This basic approach is followed throughout the first section in the examination of scanning methods and generators, picture reproduction, camera tubes, and video amplification. Mathematical derivations, while not profuse, are present whenever warranted but not in such quantity as to preclude an informative qualitative reading of the text.

Part II deals specifically with the commercial telecasting system and its problems. Each of the adopted standards is described, in each case the factors governing the choice being recognized. Separate chapters are devoted to the existing and original special problems of standardization and the work of the committees, choice of the number of lines, synchronization, vestigial-sideband transmission, transmitters, receivers, stagger-tuned amplifiers, receiving antennas, and the particular methods and difficulties of transmitting motion picture films.

The final section is an analysis of color transmission with the same basic approach—response of the eye, color matching and other optical principles concerned with color. This is followed with details of the RCA, CBS and CTI systems. An appendix furnishes a detailed analysis, principally mathematical, of the interesting case of dot systems of color transmission.

There are 18 pages of problems for the student. Footnotes throughout the book indicate a wealth of literature, mostly periodical, for additional reference, and useful subject and author indexes end the book.

This is not a book for nonelectronics people to use in beginning a television education. It is definitely, however, highly recommended as a text for the electronics engineer to employ, for both educational and reference purposes, and in designing commercial and industrial systems and components.—*Richard H. Dorf*, Television Consultant, 255 West 84th St., New York 24.

Gobo, Cuffo and Cucalorus

Words, words, words! amusing, confusing and many of them unnecessary are packed into the *TV dictionary–handbook for sponsors* just published by Sponsor magazine, 510 Madison Ave., New York, at $2.00 per copy. This 70-page booklet lists 1000 television terms and although it is probably a handy guide for newcomers to the field of television production, it threatens to kick the props out from under the Society's motion picture and television glossary project.

Many television terms have been swiped from the movies, misinterpreted, then too loosely defined. *TV dictionary–handbook* does a good job of classifying and setting the record straight, but its chief merit is its breeziness.

SMPTE Officers and Committees: The roster of Society Officers and the Committee Chairmen and Members were published in the April *Journal*.

New Members

The following members have been added to the Society's rolls since those last published. The designations of grades are the same as those used in the 1950 **Membership Directory.**

Honorary (H) Fellow (F) Active (M) Associate (A) Student (S)

Child, Harry R., Motion Picture Instructor, U. S. Army. **Mail:** 1025 E. 43 St., Austin, Tex. (A)

Einhaus, C. G., Manager, Photographic Division, Gardner-Denver Co. **Mail:** 1109½ Cherry, Quincy, Ill. (M)

Elias, Bernard L., Customer contact man, color print and film processing, Eastman Kodak Co. **Mail:** 724-A South Curson Ave., Los Angeles 36, Calif. (M)

Halliday, Kenneth N., Senior Mechanician, Test Division, Cape Town City Electricity Dept. **Mail:** 15 Wisbeach Court, Wisbeach Rd., Sea Point, Cape Town, South Africa. (A)

Heacock, R. H., Product Manager, Theatre Equipment, RCA Victor Div. **Mail:** Medford Lakes, N.J. (M)

Kortge, Kenneth M., Motion Picture Film Editor, Sound Engineer, J. R. Hunter—Capital Film Service. **Mail:** 233 S. Clemens St., Lansing 12, Mich. (A)

Lueders, Arthur L., Camera Designer, Bell & Howell Co. **Mail:** 6452 N. Bell Ave., Chicago 45, Ill. (A)

McBride, Russell R., Owner, Sound Recording and Engineering Firm. **Mail:** P.O. Box 596, Del Mar, Calif. (A)

Monson, Roger L., Projection Engineer, American Broadcasting Co. **Mail:** 2920 West Ave. 34, Los Angeles 65, Calif. (A)

Palmer, Solita, Composer, original music scores, Emerson Yorke Studio. **Mail:** 78 Engle St., Cresskill, N.J. (A)

Priebe, Roy E., Photographer and Teacher, Los Angeles Board of Education. **Mail:** 4209 W. 62 St., Los Angeles 43, Calif. (A)

Seelye, Vernon E., Equipment Repair, Capital Film Service. **Mail:** 1604 Illinois Ave., Lansing, Mich. (A)

Smith, Alan A., Process Control, Research, Warner Brothers. **Mail:** 503-B South Catalina St., Burbank, Calif. (A)

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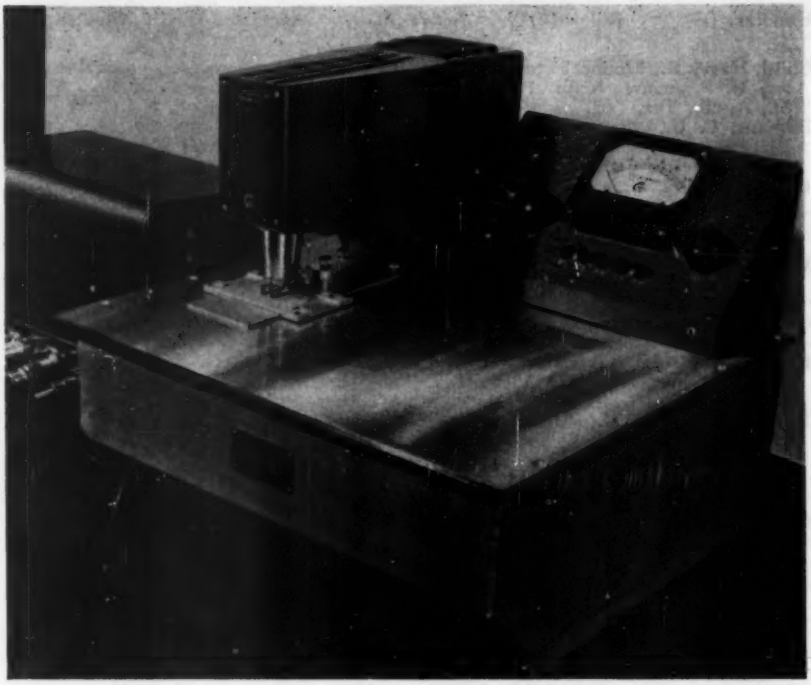

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